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Transdisciplinary Engineering: Crossing Boundaries

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Preface

This book of proceedings contains papers peer reviewed and accepted for the 23rd ISPE Inc. International Conference on Transdisciplinary (formerly: Concurrent) Engineering, held at the Federal University of Technology, Parana, Curitiba, Brazil, October 3–7, 2016. This is the fourth issue of the newly introduced series "Advances in Transdisciplinary Engineering" which publishes the proceedings of the TE (formerly: CE) conference series and accompanied events. The TE/CE conference series is organized annually by the International Society of Productivity Enhancement (ISPE, Inc.) and constitutes an important forum for international scientific exchange on concurrent engineering and collaborative enterprises. These international conferences attract a significant number of researchers, industry experts and students, as well as government representatives, who are interested in the recent advances in concurrent engineering research, advancements and applications.

Developed in the 80's, the CE approach is based on the concept that different phases of a product life cycle should be conducted concurrently and initiated as early as possible within the Product Creation Process (PCP), including the implications of this approach within the extended enterprise and networks. The main goal of CE is to increase the efficiency and effectiveness of the PCP and to reduce errors in the later phases, as well as to incorporate considerations for the full lifecycle and through-life operations. In the past decades, CE has become the substantive basic methodology in many industries (e.g., automotive, aerospace, machinery, shipbuilding, consumer goods, process industry, environmental engineering) and is also adopted in the development of new services and service support.

The initial basic CE concepts have matured and have become the foundations of many new ideas, methodologies, initiatives, approaches and tools. Generally, the current CE focus concentrates on enterprise collaboration and its many different elements; from integrating people and processes to very specific complete multi/inter/trans-disciplinary solutions. Current research on CE is driven again by many factors like increased customer demands, globalization, (international) collaboration and environmental strategies. The successful application of CE in the past opens also the perspective for future applications like overcoming natural catastrophes, sustainable mobility concepts with electrical vehicles, and intensive, integrated, data processing. Due to the increasing importance of transdisciplinarity, the board of ISPE Inc. has decided to rename the conference series in "Transdisciplinary Engineering".

The TE2016 Organizing Committee has identified 31 thematic areas within CE and launched a Call For Papers accordingly, with resulting submissions submitted from all continents of the world. The conference is entitled: "Transdisciplinary Engineering: Crossing Boundaries". This title reflects the variety of processes and methods which influences the modern product creation. Finally, the submissions as well as invited talks were collated into 17 streams led by outstanding researchers and practitioners.

The Proceedings contains 108 peer-reviewed papers by authors from 20 countries and one invited keynote paper. These papers range from the theoretical, conceptual to strongly pragmatic addressing industrial best practice. The involvement of more than

14 companies from many industries in the presented papers gives additional importance to this conference.

This book on ‘Transdisciplinary Engineering: Crossing Boundaries’ is directed at three constituencies: researchers, design practitioners, and educators. Researchers will benefit from the latest research results and knowledge of product creation processes and related methodologies. Engineering professionals and practitioners will learn from the current state of the art in concurrent engineering practice, new approaches, methods, tools and their applications. The educators in the CE community gather the latest advances and methodologies for dissemination in engineering curricula, while the community also encourages young educators to bring new ideas into the field.

The proceedings are subdivided into several parts, reflecting the themes addressed in the conference programme:

Part 1 of the Proceedings comprises the keynotes.

Part 2 is entitled Concurrent Engineering and Knowledge Exchange and contains papers on research in Concurrent Engineering and the exchange of knowledge in CE in research and practice.

Part 3 outlines the importance of Design Tools and Methods within CE. It contains several methods for managing product data and supporting the product development process.

Part 4, Engineering for Sustainability, addresses a variety of approaches to support disassembly and recycling and estimating the impact for sustainable manufacturing.

Part 5 contains papers in the theme Systems Engineering with system approaches in various application areas.

Part 6 focuses on Multi-disciplinary Product Management with an emphasis on information and project management.

Part 7 contains contributions on Collaborative Design and Engineering with methodologies for enhancing the product development process, such as design thinking and simulation.

Part 8 illustrates some approaches to Decision Support Systems. This topic is also very important in the context of CE.

Part 9 deals with the Optimization of Engineering Operations and Data Analytics, showing mathematical tools for analyzing a variety of product and design aspects.

Part 10 contains contributions on Digital Manufacturing and Process Simulation with models for supporting, simulating and improving the manufacturing process.

Part 11, Cost Engineering, contains papers on research on estimating and reducing costs in the product development process.

Part 12 addresses the theme Product Lifecycle Management with papers on integrated information systems and reusable models.

Part 13 contains contributions in the area of Service Engineering, emphasizing maintenance and reverse logistics.

Part 14 contains papers on the theme Risk Analysis and Value Engineering, an importing topic in CE.

Part 15, Multi-disciplinary Design Optimization, contains simulation and assessment methods in various application areas.

Part 16 contains papers on the theme Knowledge-based Engineering with an emphasis on modeling.

Part 17, Requirements Engineering, addresses the management and elicitation of product requirements.

Finally, part 18 addresses the theme Supply Chain Collaboration. Papers in this part present different aspects of the supply chain.

We acknowledge the high quality contributions of all authors to this book and the work of the members of the International Program Committee who assisted with the blind peer-review of the original papers submitted and presented at the conference. Readers are sincerely invited to consider all of the contributions made by this year's participants through the presentation of TE2016 papers collated into this book of proceedings. We hope that they will be further inspired in their work for disseminating their ideas for new approaches for sustainable, integrated, product development in a multi-disciplinary environment within the ISPE, Inc. community.

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Part 1

Keynotes

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Complex Project Management

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Abstract. Managing complex projects is always a challenge. During a project's life cycle, technical, cost, schedule and political complexities can arise. These challenges may include design requirement changes, resource shortages, changes in government regulations, problems with subcontractors, delays in other interdependent projects, which require detailed project plans, particular skill sets, flexibility and constant adaptability. More importantly, organizations need methods to to help managers address complex situations. System Dynamics is a method that can be applied to different areas of knowledge, especially when the system is relatively complex and the behavior of key variables is difficult to predict. This paper describes the use of System Dynamics to help project managers conduct the management process and face uncertainties and complexities. Lessons learned from a Brazilian Air Force Project Management Office - PMO are presented to illustrate insights and key lessons for decision makers.

Keywords. System Dynamics. Knowledge Management. System Thinking. Dynamic Models. Complex Projects. Lessons Learned.

Introduction

In the late 1980s, Empresa Brasileira de Aeronautica SA (Embraer) and Aermacchi launched the AMX project, a joint Italian/Brazilian program to create a lead-in fighter trainer and light attack aircraft. The result was a capable jet, especially in the light attack role, known as the AMX fighter bomber which entered into service in 1990 and had the Italian and Brazilian Air Forces as the main contractors [1].

At that time, the Brazilian Air Force Command (COMAER) created the Coordinating Committee of Combat Aircraft Program (COPAC) to manage the acquisition process and coordinate the implementation of these aircrafts in Brazil. Furthermore, COPAC became the main agency responsible for coordinating activities related to modernization and acquisition of strategic aeronautical systems for Brazilian Air Force (BAF) and currently functions as a Project Management Office (PMO) in COMAER.

Presently, COPAC manages 20-23 projects with an annual budget of around US$4 billion. Its responsibilities and activities include, among others:

- Overseeing time, cost and performance in order to adhere to contractual requirements;
- Ensuring that all work performed is both authorized and funded by contractual documentation;
- Integrating work across the operational lines, such as engineering, R&D, logistics and human resources; and

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- Ensuring that all work required is documented and distributed to all key personnel.

As these activities are carried out in these medium- and long-term projects , that is, projects lasting between 5-15 years, the management process becomes complex. There are likely to be many changes and disruptions, development of large complex systems and software, multiple integrated interfaces and interfacing with multiple complementary projects, systems and users. One tool that can help managers address these complexities is the use of System Dynamics concepts. System Dynamics is a method used to enhance learning in complex systems and can be applied to different areas of knowledge, especially when the system is relatively complex and the behavior of key variables is difficult to predict [2].

This work aims to present the use of System Dynamics concepts in managing complex projects and explore several important lessons learned in COPAC in order to share best practices and help other organizations manage their complex projects.

1. System Thinking and System Dynamics

Too often programs and projects suffer from vague and constantly changing user requirements, combined with inadequate or incomplete acceptance criteria. In this regard, COPAC has faced different project management challenges in and recognizes the necessity of new management strategies to handle these complexities. It needs tools and processes that help project managers to understand the issues, design better operating policies and guide changes in the system to improve procedures, in both simple and complex projects. The term "complex" projects refers to projects that may face challenges involving cost, schedule or performance issues, though these problems may only require constant schedule changes, requirement review and cost containment measures[3]. COPAC's projects are complex as well as large-scale, long-term and full of uncertainties.

Besides technical and schedule challenges, funding is a constant source of concern. From not having enough to the ways in which it is phased into the project's schedule, it requires constant contract renegotiations to introduce changes in schedule and technical requirements. These changes can reduce a project's critical requirements and result in a suboptimal product or service. Due to the nature of its projects, COPAC also deals with political complexities. Public funding is controlled by politicians with their own priorities, ideologies and different views of projects. This requires communication strategies with politicians that highlight public interests such as national defense, scientific achievement, public utility and employment opportunities[3]. A dynamic complexity arises from the interactions between the aforementioned factors. These effects can combine, making it difficult to see how root causes and outcomes relate. Projects often get off track and grow in cost and time without stakeholders understanding the underlying reasons.

One identified tool to deal with these complexities is the practice of System Thinking. This concept helps managers to see the "big picture" of the project life cycle, and maintain focus on its budget, schedule and end user's goals. In 2007, the Fundação Nacional da Qualidade (FNQ) conducted a virtual research with 196 Brazilian executives about System Thinking and its effective use in organizations. The results show that 45% of executives recognize the importance of this method and agree that this knowledge should be used intensively. A mere 22% use it effectively. This research reveals a lack of knowledge in terms of how to effectively use System Thinking.

These numbers do not differ significantly in the Brazilian Air Force. This is mainly because the majority of officers receive only basic System Thinking concepts during their military training and there is a lack of the practical application of this strategic approach. To minimize these knowledge gaps, COPAC recognized the importance of practicing System Thinking along the entire project's life cycle and as a skill that managers should acquire or develop. Therefore, in 2011, COPAC started a new internal project regarding knowledge management and one of the main objectives, among others, was to develop the System Thinking practice in projects management.

The practice of system thinking needs a common language to express multiple relationships in a system. In general, we are taught to see linear relations; one cause produces one or several consequences in a linear cause and effect chain. Most of our models that try to explain a system do so through a linear view, which can bias our understanding of the system. Of course, there is not only one technical approach to understanding complexity in systems and projects. Yet there must be a starting point, an educational model to inform others in the field and, from that, develop a methodology that remains true to the context in which the process is practiced and experienced.

In COPAC, this educational model was the System Dynamics methodology and it helped managers to have a dynamic perspective on their projects, problems and issues. System Dynamics can be defined as a methodology and a mathematical modeling technique to understand the behavior of complex systems over time. This approach seeks to understand a system's structures, interconnections between all components, feedback loops and how time delays will affect the whole system and its constituent parts. One aspect of System Dynamics that helps managers to analyze complexities is the extensive use of models that can represent the relationships, time delays, behaviors and causalities of a system.

2. Mental Models

Every professional or stakeholder involved in a project has a mental model, consisting of their expectations about an issue. In other words, these mental models consist of managerial frameworks, mindsets, paradigms, conventional wisdom, and assumptions. Different mental models can be useful because they allow us to process information, access past experiences and discover new opportunities. But, they can also cause great difficulties in the decision making process and can contain psychological biases[2]. These are the main problems in most of COPAC's projects and the consequences include reworks, schedule delays and changes in costs.

[2] What is Psychological Bias? Psychologists Daniel Kahneman, Paul Slovic, and Amos Tversky introduced the concept of psychological bias in the early 1970s. They published their findings in their 1982 book, "Judgment Under Uncertainty."They explained that psychological bias – also known as cognitive bias – is the tendency to make decisions or take action in an illogical way. For example, you might subconsciously make selective use of data, or you might feel pressured to make a decision by powerful colleagues. Psychological bias is the opposite of common sense and clear, measured judgment. It can lead to missed opportunities and poor decision making. (https://www.mindtools.com/pages/article/avoiding-psychological-bias.htm)

An example that illustrates the importances of mental models occurred during a modernization program of a brazilian maritime patrol aircraft. Four years after the contract was signed, the main service supplier made a financial compensation claim due to losses, citing a deviation in the contract execution, caused by constant requirement changes, delayed payments and technological issues. On the other hand, BAF countered that the delays and increased costs were the result of supplier's quality issues that caused reworks and faulty deliverables. Essentially, the supplier and BAF disagreed over the delays and cost overrun because their mental models were different. The use of System Dynamics models, Causal Loop and Stock and Flow diagrams, provided a shared view to both sides, helped managers and technical personnel to understand the sources of the problems and provided alternatives to solve the contest.

Causal Loop Diagrams and Stock and Flow diagrams are part of the System Dynamics' toolbox and they were used to facilitate dynamical analysis via simulation. A detailed explanation about these tools can be found in the extensive literature, but one recommended reference is John Stearman's book, called *Business Dynamics: Systems Thinking and Modeling for a Complex World*[2].

The System Thinking and System Dynamics first helped COPAC's officers to see a particular structure underlying a particular problem in the organization. Managers start thinking in terms of the system "archetypes".

3. A System Archetype

Initially within the COMAER structure, COPAC grew fast and gained a certain credibility in coordinating and managing the main acquisition and development programs in the Brazilian Air Force. Its members developed skills and processes to manage complex projects such as the AMX fighter-bomber. Due to its quality and efficient methods, it has received support and recognition from different organizations. Officers are respected by their developed management skills and junior officers are highly motivated because of the promotion opportunities. But, eventually, systems and processes became increasingly complex and difficult to manage. With more projects under COPAC's supervision, the management burden often falls on the most experienced officers, who in turn have less time to pass on or teach their past experiences and knowledge to less experienced officers. As a consequence, more errors occur, such as incomplete requirements, faulty contracts and reworks. The consequences were costly and time consuming projects.

To resolve these issues, there were quick solutions. Senior and more experienced officers were redirected to work on problematic areas, double checking past actions and procedures. By increasing their workload but not releasing them from their daily responsibilities, they became the "heroes" or super managers acting to solve COPAC's issues. The organizational culture in the Brazilian Air Force values hard workers. There is an unwritten norm that real heroes are the officers that work over forty hours a week, stay late at the office and are available at all hours. It is a culture that produces good results, but can blind workers to certain types of problems. Officers act directly in response to the symptoms of a problem (managing errors), releasing the pressure in the organization. However, doing this, they bypass the processes that made COPAC's growth, such as the research and development (R&D) of new skills and processes to face new challenges and uncertainties in projects.

Systems Thinking provides insights that help us understand certain recurring structure patterns, called System Archetypes, that explain common management situations. Researchers have identified a dozen system archetypes [4], but one of them can be used to enlighten COPAC's historical context, known as "shift the burden".

Figure 1, shows this archetype, there are two processes and both try to adjust or correct the same problem (e.g. errors in managing projects). The symptomatic solution (top circle) solves the problem quickly, but only temporarily. The fundamental solution (botton circle) works far more effectively, but has a delay, so it takes longer to become evident.

In shifting the burden, a side effect appears from the symptomatic solution, people rely more and more on the symptomatic solution [4], making matters worse in the long term and, at times, top managers are uninvolved due to other career demands or even retirement. The gap between a fundamental solution (e.g. train junior officers and support R&D), and the symptomatic solution (e.g. pressure senior officers to solve urgent problems), becomes worse because sufficiently experienced managers and knowledge are not retained to help those remaining in the organization.

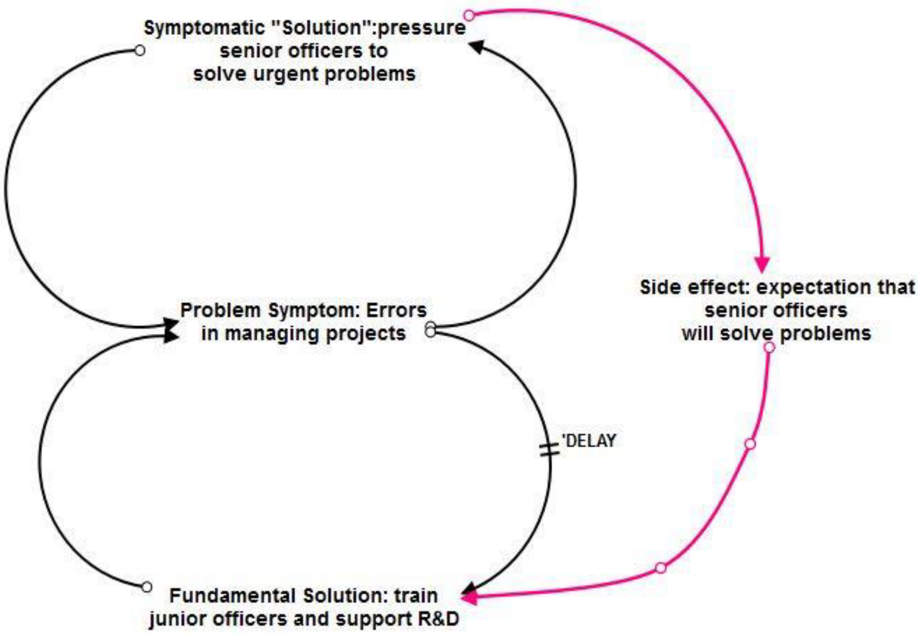

Figure 1. Shift the burden archetype, adapted from Senge [4].

In his book "The fifth discipline: The art and practice of the learning organizations" Peter Senge [4] discusses why systemic insight are not incorporated in operating policies. Even if a pilot experiment proves successful and a new approach leads to better results, widespread adoption of the approach rarely occurs. He explains that new insights fail to get put into practice because they conflict with deeply held internal images of how the world works (mental models); these images limit us to familiar ways of thinking and testing rather than allowing us to challenge and question the world around us.

In the COPAC example, these problems came from inadequate or incomplete mental models. These models, developed over time through experience, can act as filters that screen incoming information and make us hear what already supports our existing beliefs and ways of operating. Meanwhile, any new information that does not support what we believe is discarded as wrong or not applicable. In BAF, high-rank officers believed the solution should come from increasing the workload of the senior managers.

The solution for this archetype was to to improve junior officers training and the knowledge management in the organization. Basically, explaining to high-rank officers the logic of this model, what was occurring and the long-term consequences in order to support the fundamental solution (Figure 1).

In this context, the analysis of works presented by Tavares [5] and Bonotto [6], describes the knowledge production and project management´s vulnerabilities in COPAC. Through these works, an important issue could be also identified: the loss of organizational knowledge due to the departure of skilled staff. So, an internal initiative was established.

4. Knowledge Management

Like other types[3] of knowledge, the management of these assets is not an easy task. Organizational knowledge, whether explicit or implicit, is an abstract entity inherent to humans and is not transferred or shared with ease or spontaneity [7]. Unlike the administration of physical resources (material, human and financial), which can be measured and controlled, organizational knowledge is subjective, is not well defined and conceptualized, and lacks explicit indicators.

Different authors define Knowledge Management in different contexts and for different purposes; they conceptualize the term in different ways based on different epistemologies. Therefore, for this paper, the definition used incorporates an interdisciplinary perspective that considers the dynamic nature of Knowledge Management, and will be defined as:

The effective learning processes associated with exploration, exploitation and sharing of human knowledge (tacit and explicit) that uses appropriate technology and cultural environments to enhance an organization’s intellectual capital and performance [8].

According to Nonaka and Takeuchi [9] there are two types of knowledge, tacit (implicit) and explicit knowledge. Tacit knowledge consists of one's experiences, mental models, beliefs and opinions. Explicit knowledge is a kind of knowledge that can be defined and shared easily through information technology. With these two concepts, Nonaka and Takeuchi have developed a theoretical dynamic model as shown in Figure 2, known as SECI (Socialization, Externalization, Combination and Internalization). This framework is based in studies on the Theory of Organizational Knowledge Creation [9].

[3] Popular, philosophical, religious or scientific.

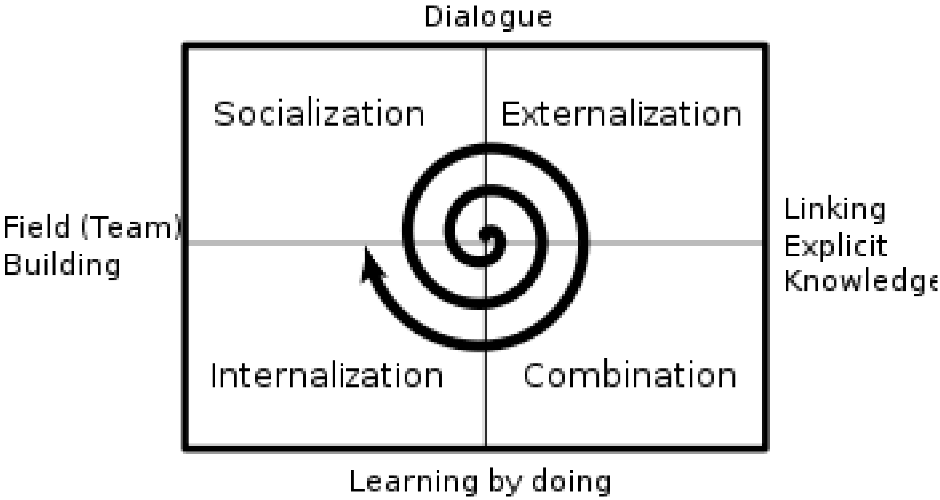

Figure 2. Nonaka and Takeuchi SECI model [9].

These two authors argue that knowledge is initially created by individuals and becomes organizational knowledge through a spiral process described by the theory (see Figure 2).

This spiral is created by the four modes of knowledge conversion through which knowledge is converted from one knowledge type to another. The modes of knowledge conversion include socialization (from tacit to tacit knowledge), externalization (from tacit to explicit knowledge), combination (from explicit to explicit knowledge), and internalization (from explicit to tacit knowledge).

The SECI model is dynamic [10]; humans play an important role and organizational networks generate knowledge through social processes of sharing, exploration and creation of tacit knowledge (stories, experiences and concepts) and explicit knowledge (raw data, bank and organized data reports).

Peter Massingham [11] also explores this issue in a case study within the Australian Ministry of Defense. In this work, the author simulates the consequences of the departure of important personnel and discusses the results of this research in the context of existing literature. In his conclusion, he presents a preliminary conceptual model in order to identify and isolate the causes and nature of the risks involved.

An important tool, in terms of knowledge management and part of COPAC's initiative, is the registry of "Lessons learned". This was an effort to create, among project managers, a habit of incorporating a process of lesson learning during the life cycle of the project, not only at its end. This process attempts to make knowledge be processed by the four modes of knowledge conversion. For instance, every week a subject or a case study is presented to managers or junior officers during a general meeting (Externalization), a topic is also created in the private network to allow discussion and exchange of experiences (Combination), the important insights are captured and registered for public research (Internalization) and communities of practice are formally recognized to promote informal meeting (Socialization).

Lessons learning means that at each key milestone, people involved with the project pause to review assumptions, evaluate changes in the internal and external environment and review risks and estimates. In this way, knowledge is spread through the entire organization.

The goal is to adapt the project plans to any changes that will impact the final objective with the shared knowledge created by the collective experience. There is a constant need to preserve experiences and accumulated memories during the management process. This implicit knowledge, combined with explicit knowledge (e.g. policies, guidelines and manuals), builds COPAC's organizational knowledge which permeates all its activities and most of this knowledge resides in the minds of its members and leaders, from past and present.

5. Conclusions

In today's world, technology changes faster than the pace of the project. Managing complex projects is always a challenge and during the entire project life cycle, there are technical, cost, schedule and political complexities. It requires management strategies that can help managers address the uncertainties and complexities in a project.

This article presented some aspects of the use of System Dynamics and the lessons learned approach along the existence of a PMO in the Brazilian Air Force Command in order to help other organizations in their project management initiatives.

As a PMO, COPAC needs to move everyone in the same direction. However, two people may look at the same problem and derive different viewpoints based on their own experiences. Suggesting a System Dynamics approach, adding concepts of delays and feedbacks loops, is not to deny people's mental model, but instead, to help them develop and improve models with a system thinking view.

System Thinking and System Dynamics help managers to routinely question their mental models. This does not necessarily means abandoning their beliefs or past experiences, but requires them to think actively about assumptions we make about a problem, a project or a program.

Another key point to manage these projects is to understand where the complexity originates from. This demands a System Thinking view to see the whole instead of the parts and helps managers to identify the relationships and consequences of decisions made. This knowledge is an important asset and has strategic value for the whole organization.

One way to preserve this knowledge is through knowledge management initiatives, especially in the form of "Lessons learned," which acknowledges that there are takeaways can learned from each and every project, from simple insights to strategic conclusions that can be usefully applied on future projects.

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Part 2

Concurrent Engineering and Knowledge Exchange

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Transdisciplinary Engineering: Crossing Boundaries
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Managing Risks in Knowledge Exchange: Trade-Offs and Interdependencies

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Abstract. Knowledge exchange, as required in Trans-disciplinary Engineering processes (TE) is not without risk. Many types and sources of risk exist, which depend on the type of interdependency between actors (companies) in TE teams as well as on the strategic nature of the knowledge exchanged. Risks need to be managed, not only with technical means, but also with other types of methods, like contracts. In this paper, different types of interdependencies are described which influence the risks that actors may encounter. Moreover, in managing risks, different trade-offs arise, which complicate the choice of a suitable method. In the paper, an introduction to different types of contractual solutions is presented, which need to be extended in further research.

Keywords. Trans-disciplinary Engineering, Knowledge Exchange, Intellectual Property

Introduction

Trans-disciplinary Engineering (TE) is a logical consequence of the concept of Concurrent Engineering. It more closely emphasizes the need for different disciplines to collaborate across intra- and inter-company borders. Such collaboration already starts with the conception of an idea until the release of the product for production and service. Destruction or take-back for recovery also need to be taken into account during the TE process. Not only engineering disciplines are involved in collaboration, but also marketing, production, maintenance and service, sales, and representatives of end-user communities, including legal and financial entities. TE as such is an encompassing concept, requiring extensive technical and organizational solutions for making it work.

A complex concept like TE is difficult to implement in practice. It takes many years to take the necessary steps to master the many challenges that accompany TE (see amongst others [1]). There are also many trade-offs to be made because, for various reasons, optimization of products, processes and organization is often not possible. First of all, legislation of the different countries involved may inhibit optimal ways of working. Second, people may inhibit optimization because of differences in cultures and working habits. Third, the openness between departments and companies as required in optimal TE may endanger company assets, especially valuable knowledge assets. This last point will be the subject of this paper. We will discuss the potential

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risks of TE with respect to knowledge exchange, as has been discussed before elsewhere [2]. We propose contractual solutions for managing the risks of knowledge exchange as is needed in the design process. Contracts in this context refer to both formal and verbal contracts, as well as investment-based contracts, like equity alliances or vertical integration [3].

The paper is organized as follows. In section 1, the history of CE towards TE is briefly described. Section 2 discusses in more detail the problem with free knowledge exchange as is required in TE. In section 3, a framework of contractual solutions is presented for managing risk in transactions between companies [3]. The framework is a proposed extension of the Transaction Costs Economics framework (TCE) of Williamson [4]. We will discuss possible contract forms for managing risks in knowledge exchange. Section 4 contains a summary and ideas for further research.

1. TE follows CE

In this section a brief history of CE is presented (section 1.1) as well as an explanation of the concept of TE (section 1.2).

1.1. Brief history of CE

The concept of Concurrent Engineering (CE) has been developed in the early 1980s. Initially, the emphasis was on the parallel execution of design and manufacturing processes to limit the number of design failures later in production. The notion of concurrency has been valid until now. Gradually, the emphasis has shifted to collaboration, because collaboration and teamwork is deemed crucial, especially because also the number of disciplines involved has gradually grown, while also the intra-company focus has been extended into an inter-company focus. In the early stages of CE the design had to take into account the manufacturing and production phases. Later, the whole lifecycle of a product became important in the design phase, including the idea development and after-sales activities like maintenance and repair and also asset recovery. Users, consumers, and other stakeholders, play a role now in current CE.

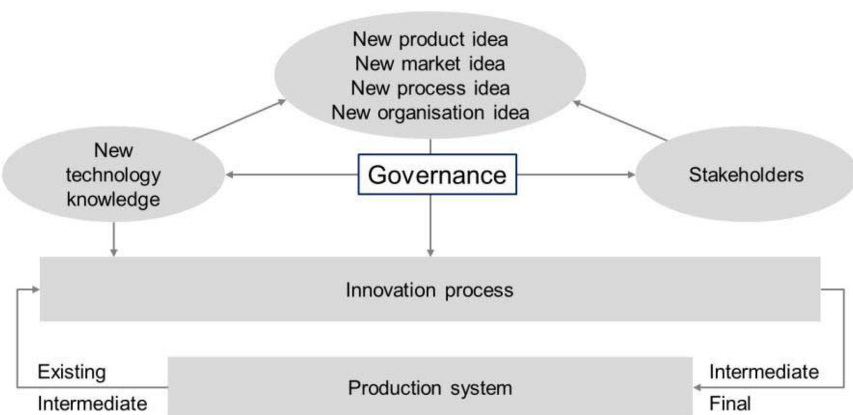

Figure 1. The system of CE [Wognum and Trienekens, 2015].

In Figure 1, the whole trajectory of CE is depicted [1]. In this figure, the start of a CE process is a new idea, possibly based on new technology or created with the help of stakeholders. The new idea can be a product, market, process or new organization idea or two or more of these together. The CE process, which can also be understood as an (open) innovation process needs to be governed by means of a suitable organization and organizational arrangement like teams, procedures, and mutual agreements between the stakeholders. The figure also emphasizes that the intermediate and final outcome of a CE process is a production system that is aimed to produce the intended products and/or services. The production system can be new, for example a new company or supply chain, but can also be an existing one, adapted for the new product.

1.2. From CE to TE

The concept of CE is characterized by a focus on customer requirements and embodies the belief that quality is a result of continuous improvement of a process [5]. Teamwork, as has been indicated above, is central to this approach. Teams may be at geographically different, networked, locations. This fact complicates CE because many different cultures, values, disciplines, functions, and technologies need to be aligned. CE is these situations, which more predominantly exist today, can be characterized as Trans-disciplinary Engineering (TE).

To achieve integrated, parallel, product and process design strategies, logistics, and functions need to be aligned as is indicated in Figure 1. Advanced information management systems are needed for enabling and supporting such integration. Such systems support intra- and inter-company collaboration and enable exchange of knowledge in the form of product, process and service models.

An example of a platform for information management for TE is SORCER [5]. Platforms like SORCER are able to support alignment of different proprietary information systems and exchange and processing of product models. In the next sections we will discuss some issues that accompany the exchange of models and knowledge, which constitute often the intellectual property of companies involved.

2. Trade-offs in knowledge exchange

A large part of intangible assets like knowledge of new technology and complex product models that are valuable for a company is called Intellectual Property (IP). Intellectual property is a broad label for the set of intangibles owned and legally protected by an enterprise from outside use of implementation without consent [2]. It consists of the business know-how (product, process, service) and rights (patents, trade secrets, copyrights and trademarks) [6]. Together these assets can be more valuable than companies' tangible assets.

The extensive exchange of knowledge through information systems is a feature of well-implemented TE [2]. It provides high transparency of processes, models and data, but as such forms an additional threat for the safeguarding of IP. Incidents are reported, such as product piracy, plagiarism, counterfeits, theft of data, and cyber crime [7]. It is, however, often difficult to identify violation of IP because of differences in political systems, organizational and technical constraints, and socio-economic situations [8].

Protection of IP in a TE world requires measures that take into account:

- The measures to be taken at each site [2],

- Integration of these measures into the overall product lifecycle management [2][9],
- Dependencies between companies in network or supply chain involved (see section 4) [3][10].

Some trade-offs need to be considered in managing risks in IP protection [2]. First of all, companies may have local competitive advantage, which they may loose when they 'go global'. A typical example is a supplier who participates in bidding for a concept solution for a new customer (OEM) in a country with low legal protection against IP violations, where the customer can easily distribute all knowhow presented by bidders to the bidder with the best commercial conditions (e.g., the lowest price). The local bidders can heavily learn and upgrade their know-how by participating in such a competition. However, local politics may prevent them from doing so. Second, social media make it extremely more difficult to restrict the free exchange of knowledge. Third, a choice needs to be made between the degree of policing and the degree of sharing. Fourth, it is not easy to decide which data are confidential and which are public. Fifth, costs of implementing measures against potential violation must be balanced against potential losses. Fifth, when multiple risks can be encountered, as is often the case in TE processes, a trade-off needs to be made for which risk to manage.

Stjepandic et al. [2] have described some technical approached for managing risks. For example, an OEM would allow the use of rich clients of their PDM system only at the supplier site. In this way, secure access is realized to the OEM's engineering database because of standardized processes like authorization and authentication of single users and devices. However, integration between the systems involved is prohibited in this way leading to large data queues at the supplier site.

Another technical approach is the management of patents. A patent is an IPR granted with exclusive rights for commercialization and can potentially bring huge benefit to an enterprise. Management of patents is aimed at reducing the risk of infringement. A variety of management approaches exists. Patent infringement analysis should be conducted frequently during a patent lifecycle. Suitable IT systems support this analysis, such as systems based on patent ontology engineering [2].

Protection of product data is another measure that can be taken. Artificial Intelligence (AI) offers techniques for improving CAD systems and PDM systems. AI covers methods for acquiring, processing and storing of knowledge. Knowledge-Based Engineering (KBE) technologies can be embedded in CAD and PDM systems. Embedded systems enable interaction of comprehensive product-specific knowledge and know-how in a single model. To manage risks associated with misuse and loss of models, the flow of knowledge has to be controlled in a predefined and traceable way.

Reverse engineering is another threat for misuse of IPR. One of the action fields of IPR is to disable this route.

In the next section a framework for risk management is discussed, which has been developed in the context of transactions between actors, which can be traders, different companies in a network or suppliers and customers in a supply chain.

3. A framework of contractual solutions

Companies, supply chains, business networks and economies have become more interdependent. as shown by the 2007-2008 financial crisis [3]. Insufficient monitoring of the actions of individual companies or actors has led to the bankruptcy of banks and other financial institutions [3]. In TE environments protection of intellectual property rights (IPR) requires attention, because violation of IPR may cause not only much harm to the owner company, but also to all companies in the network or supply chain that are dependent on the results of a TE process.

In the next section, various types of interdependencies are specified and discussed. Differences in interdependency expose actors to different sources of risk. In the subsequent section three possible risk management strategies are discussed. The discussion is based on a framework for risk management that has been developed as an extension of the Transaction Cost Economics (TCE) framework [3; 4; 11].

3.1. Dependencies between actors in a TE process

In a TE environment companies are related in three basic ways: pooled, sequential, or reciprocal [12]:

- Companies in a pooled interdependency are relatively independent to each other, but share a common resource, like a financial resource, or a service provider. Misbehaviors by one of the members of the pool may damage the working of the pool by lost image and reputation. Conversely, when the resource is unavailable or produces low quality, all members are affected;
- Companies in a supply chain have sequential relationships. The output of one company is input for another. Often the receiver of the output cannot proceed when the supplier has not finished its output;
- Companies with reciprocal relationships can be found in networks that collaboratively work in a product development project. These companies depend on each other's input and output.

In a product development process, companies may be related in more than one way. For example, companies in a network with reciprocal relationships may also have sequential relationships. This is the case, when also manufacturers are involved in the network, which is certainly true for TE projects. In addition, service providers may be involved in a TE process, because of the information management infrastructure that is used, providing the companies involved with a pooled relationship. In the aerospace industry or in the food industry, quality management institutions may exist that act as a resource pool, which monitors behavior of individual companies in the network and may prevent bad actors from participating in the network.

In Figure 2, a situation is depicted of an OEM that participates in a TE network for the development of a new product, process, or service. It collaborates with its main supplier. OEM could tie its supplier to the collaboration with a strict contract in which it prohibits the supplier to use the results for other OEMs. Conversely, the supplier could protect its own knowledge from misuse by OEM. OEM also collaborates with a technology start-up that has developed alternative technology. OEM could decide to horizontally bind the start-up so that it becomes part of OEM. In this way leakage of knowledge is basically avoided. A service provider may play the role of service pool for the network. For each actor in the network specific authorizations are installed. A certification body is another pooled resource, for example, when the network wishes to develop a new product and process that satisfies strict environmental rules.

As indicated above risks taken in one place of the network or supply chain may affect other parts of the network or supply chain. Although pooled interdependencies seem the least intensive form of relationship, damages to a shared pool of resources will affect all actors [3; 13]. Collective action, such as a quality management body, is needed to prevent such harmful outcomes, as there is little that individual actors can do to prevent such outcomes.

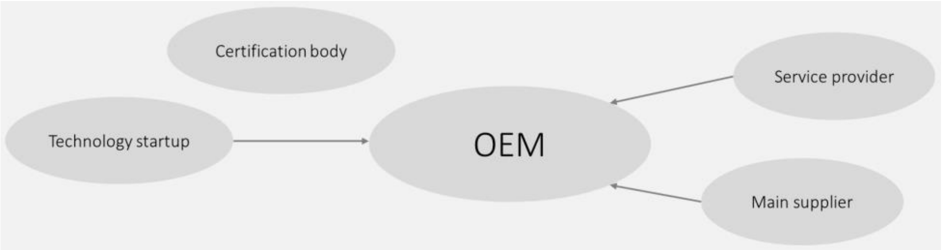

Figure 2. A possible configuration of a TE network with contracts

In sequential relationships, risks taken in one place of the supply chain may affect other parts. An example is the so-called bullwhip effect, where the increase in demand-order variability for upstream stages is due to decreasing insight into (final) demand information [14; 15]. In a TE environment, knowledge use in the manufacturing phase may create the risk of violation of IPR of another company that provided this knowledge in the development phase.

Reciprocal interdependencies are the most intensive. Actors heavily rely on each other, although risks may not be equally harmful to actors in the network. Nevertheless, the risk of strategic, self-interested behavior may decrease when interdependencies become more reciprocal. However, when circumstances change, actors need to put much effort in mutually adjusting themselves. In such cases effects may be amplified.

Risks are often associated with the degree of asset specificity, including high investments in technology needed for the TE process. High asset specificity ties actors to the network or supply chain, while it makes them more vulnerable to changes in the environment. In addition, the degree to which actors can monitor and measure behavior of other actors also influences the risks actors may encounter, like shirking (falsely claiming compliance with conditions) or opportunism (renegotiating conditions of the collaboration).

3.2. Risk management strategies in a TE context

In TE processes actors may have multiple interdependencies with the other actors participating in the process, making them vulnerable to multiple sources of risks. Trade-offs arise in deciding which sources of risk require the most attention, taking into account the costs of implementing suitable solutions, like contracts, to reduce the odds of the risk occurring or its impact.

Risks can be defined as the possibility of a harmful event (cost or loss) [16; 17]. In this paper the focus in on transaction of knowledge (product, process, and service models) as is needed in a TE process. Uncertainty may exist about the nature of the event or about the frequency of occurrence.

Three options can be distinguished [3] for managing risk:

1. Obtaining information to reduce uncertainty about the expected frequency or nature of the event;
2. Affect the probability that event occurs or affects the actor;
3. Minimize the impact when the event occurs.

The main risks that have been examined in the TCE framework are related to the strategic, self-interested behavior of actors, such as opportunism or shirking (see [3;

11]). Such behavior is possible because contracts are never complete: they always contain gaps and omissions. Information processing limitations [18] hamper actors' ability to anticipate and specify all possible situations or contingencies that may arise. In addition, a further risk is that actors in pools, networks, or supply chains may not be able to adapt when circumstances change, i.e., the risk of maladaptation.

Risks associated with opportunism are largest when actors have heavily invested specifically for the collaboration in which they act. This investment ties the actor to the collaboration. Risks associated with shirking are largest with high levels of performance measurement difficulty, referring to the extent to which an actor can measure the benefits and costs other actors bring to the collaboration. Risks associated with maladaptation are largest when collaboration is characterized by high uncertainty. High uncertainty refers to unanticipated changes in the environment of the collaboration (see [3]).

Wever et al. [3] describe four different manners in which contractual solutions can be used to manage risks. Although based on a supply chain context, these solutions are assumed applicable in a wider context, like TE.

First, actors can use contracts to minimize or reduce their risk exposure in collaborations. One way is by implementing hierarchical types of contracts, with legally binding safeguards. Such safeguards reduce the ability of actors to renegotiate conditions once specific investments are made. Moreover, the use of these contracts reduces the risks of shirking, by increasing actor's ability to monitor the other actors' performance. An example is a temporary virtual organization with legal contracts between actors.

Second, contracts can be structured in such a way that actors' incentives to act opportunistically or shirk are minimized. Sharing exposure to risk is a one way to do this. Mutual dependency of actors is a key aspect of risk sharing. Important for this strategy is that asymmetries between actors are reduced. When actors have made investments for the collaboration, they have committed themselves to the collaboration and thus have a stake in possible success. Conversely, they share the risk when outcomes are not successful.

Third, contracts may also be used to alter risk exposure, as when an actor swaps one type of risk for another. For example, as when contracts with strict conditions reduce the risk of opportunism, but at the same time increase the risk of maladaptation when actors operate in highly uncertain environments. Then, the actor's risk exposure has been altered from exposure to opportunism to exposure to maladaptation.

Fourth, risk can be transferred to or absorbed by other actors in the collaboration. In this case, 'the holder' of a risk has changed. For example, as when the exposure to price uncertainty is transferred from one actor participating in the TE process to another actor (e.g., by means of a fixed price contract).

The risks to which actors are exposed depend on the various dependencies they have with other actors in the TE process and how strong these dependencies are. For an OEM, with a strong incentive for undertaking the TE process, because of the high returns expected when successful, opening up its proprietary knowledge in the collaboration may be very risky. It may create a virtual organization with proper safeguards in which other actors participate that share the risk by opening up their proprietary knowledge in the collaboration. The risk of theft or counterfeit might then be reduced. The potential manufacturer of the envisioned end product could be part of the virtual organization or may even be vertically integrated with OEM to reduce uncertainty with respect to strategic behavior. However, proper safeguards need to be installed for the suppliers of the manufacturer depending on the type of products they deliver to the manufacturer. For commodity type suppliers, relatively simple, but strict contracts are likely to suffice. For strategic suppliers more complex, but elastic contracts are usually needed.

However, note that in a virtual enterprise fundamentally opposing interests may exist of the actors involved. OEM commissions its suppliers or external service providers to provide components or explicit services. In principle, OEM is interested in the whole of technology and know-how resulting from the collaboration. Suppliers, on the other hand, may complain that draft designs they deliver to OEM in the concept definition phase were given to their competitors in a later phase. Similarly, suppliers may want to use the developments of one project for another project with another OEM. In this case, the first OEM is the financer and client of the new development, but at the same time supports indirectly its competitors without proper safeguards.

A list of contractual risk management strategies in a TE context is shown in Tab. 1.

Table 1. Examples of contractual risk management strategies in a TE context.

	Risk minimizing	Risk sharing	Risk altering	Risk transferring
Risk exposure ex ante	OEM has developed proprietary technology that its main supplier could appropriate and use in transactions with other OEMs.	OEM is investing in technology that could become the industry standard. It runs the risk that it fails to become widely adopted.	A spot-price contract is in place between a component supplier and OEM. The latter is exposed to the risk of price increases for the components, while the former to the risk of price decreases.	OEM runs the risk of losing a large amount of money when the product development project fails due to bankruptcy of its partner
Contractual intervention	OEM integrates the supplier into its operations.	OEM enters into an alliance or joint venture with another OEM.	The parties swap the spot-price contract for a fixed-price contract.	OEM can enter into an insurance contract with an insurance company
Risk exposure ex post	By taking-over the supplier, OEM has reduced the risk of misuse of its technology.	The risk of product failure is shared amongst the two OEMs	OEM is exposed to the risk of decreases in the price of the components (as it will have locked in a higher price), and the latter to the risk of price increases (as it will have locked in a lower price).	The risk of failure is transferred to the insurance company

At least, in defining suitable measure for managing risks, direct costs and opportunity costs need to be distinguished which can be ex-ante costs or ex-post costs [3].

3.3. An example of a technical solution

Each OEM (receiver of goods or services in a supply chain) is interested to outsource as much work and as little knowhow as possible to its suppliers. In case of a significant amount of sensible product data to be exchanged, just two alternatives exist: the suppliers may access these data at the OEM's site (which is difficult to implement from physical distance) or the OEM implements a comprehensive data exchange solution, which provides a significant level of protection for both parties.

A frequently used scenario is Engineering Change Management, which occurs in the later phase of product development, the production and service phase of the product lifecycle. A typical solution to manage data exchange in this scenario is shown in Figure 3.

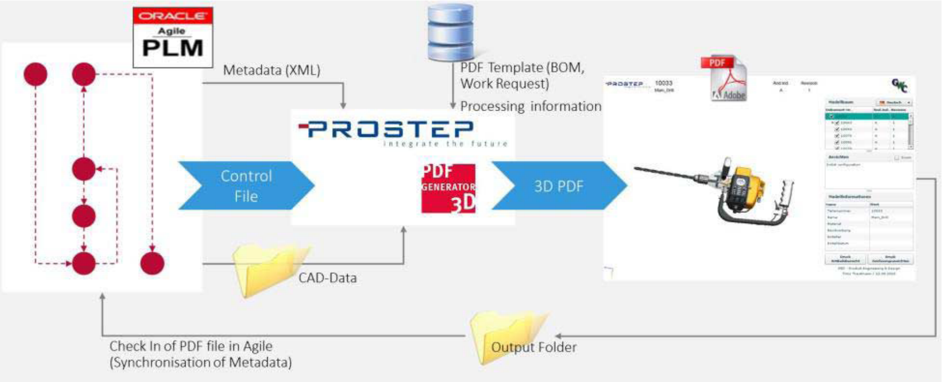

Figure 3. Data exchange to supply chain controlled by data extent and policy

An OEM (at the left side) deploys a comprehensive PDM system for product data management. In this scenario, a subset of necessary data is built by using an intelligent template with 3D PDF models. CAD data are translated to 3D PDF including product-manufacturing information (PMI) and embedded in the template [19]. Meta-information is stored in the template itself that may have several restrictions in access (time period, user or machine). The supplier can use low-cost software to insert his comments. In this way, the risk of data loss or unauthorized access is reduced to a minimum, allowing a stable and reliable communication.

4. Summary and further research

In this paper TE has been described as a concept in which multi-site, multi-disciplinary and multi-functional teams are central. Such teams collaborate by exchanging knowledge (product, process, service) and rights (patents, trade secrets, copyrights and trademarks). Exchange of knowledge is enabled and supported by advanced information management systems.

Knowledge exchange as required in TE processes is not free of risks. Risk may exist in terms of product piracy, plagiarism, counterfeits, theft of data, and cyber crime. The risks that actors encounter in a TE process depend on the type of interdependencies that they have. Three types of interdependencies have been described: pooled, sequential and reciprocal. In TE projects, actors are often interdependent in all three ways, making them vulnerable to multiple sources of risk.

Managing risks is challenging, not only because of the multiple sources of risks, but also because of the trade-offs that arise in choosing a method to deal with the risk. In addition, the type of interdependency influences the degree of adaptability to changing circumstances and the ability to measure the performance of other actors, thus influencing the predictability of risks.

Several technical solutions exist to manage risks in knowledge exchanges. These solutions are not sufficient. Different types of contracts exist that can be used to manage actors' exposure to risk. In essence, three ways of risk management can be distinguished: risk transferring, risk altering, and risk sharing.

The paper has addressed ways in which risk management in TE processes can be realized. However, more research is needed to study existing TE processes with the lens of risk management and interdependencies. A more refined definition of risk management situations than presented in this paper is needed to study existing processes (see e.g., [3; 20]). From such studies, normative models may emerge that will help companies in TE processes to anticipate, manipulate, and minimize risk. In addition, technical solutions need to be embedded in encompassing measures to manage risks.

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Parallel Engineering: Our Next Step

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Abstract. Rapidly increasing diversification calls for a new industry fraework. Traditional framwork was linear and sequential. Concurrent Engineering worked very well in these environments to reduce time to market. But to meet widely diversifying requirements, we have to develop another framework to adapt to this situation. Parallel Engineering is proposed. It will enable us to adapt quickly to the changes and we can explore new markets. This framework pivots on emerging technologies in material and in networking. Parts companies will play a central role and by combining these parts, any products can be realized to meet personal preferences and needs of customers.

Keywords. Concurrent Engineering, Diversification, Personalization, New industry framework, Parallel Engineering.

Introduction

Concurrent Engineering (CE) [1] is focused on effectiveness, speed and faster to market. The word "concurrent" came from concurrent computing or concurrent processing [2]. It implies to carry out processes at the same time, which are originally supposed to be processed sequentially. CE was very effective yesterday, when situations did not change appreciably. But today changes are frequent and extensive, so flexibility and fast adaptability are more needed.

This paper points out that industries should move ouf of CE and they should introduce another idea of parallel computing [3] into their framework. Concurrent computing executes computations concurrently instead of sequentially, while parallel computing carries out many calculations simultaneouly.

At the time of CE, industry framework is final-product-based. But such a framework needs a large factory, equipment and many expert workers so that the amount of investment is quite large. Therefore, it is difficult to change their final products, once the production starts.

But if we introduce the idea of parallel computing and develop a new Parallel Engineering (PE) framework, we can secure flexibility and fast adaptiveness. PE will be parts-company-centric and almost any final product can be realized by combining parts. So parts companies can take the initiative in securing a wide variety of final-product customers. Thus, such a new framework is not only flexible and adaptive to the frequent and extensive changes, but the markets of these parts companies will become far larger than those of the current final-product companies. Besides, they do not need such large factories as those of final-product companies and in addition, they do not need so many expert workers. Thus, cost can be reduced to a great extent,

To make such a framework really effective, we have to share knowledge and experience across applications and across industries and make efforts to develop

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versatile parts. To achieve this goal, we have to modularize our product design and share common parts or modules across different applications and across different industries.

It also must be stressed that such modular design will allow customer engagement in design and production and will satisfy their needs of self-actualization [4] and their intrinsic motivations [5]. Therefore, it is strongly expected that our customers will be more attached to our products and will be lifelong customers.

Thus, Parallel Engineering is not only a lifetime value engineering, but a versatile engineering. Concurrent Engineering is, on the other hand, a one-time value engineering on a single track.

1. Concurrent Engineering

The name "Concurrent Engineering" became very popular, since DARPA initiated DARPA's Initiative in Concurrent Engineering (DICE) Project in 1989 [1]. Its motivation was to make US competitive in war. If US finds out that Enemy is developing a better weapon, US has to develop a weapon with the same or preferably better capabilities by the time Enemy realizes it.

So the goal is very clear. Reduction of time to completion with the currently available resources (Figure 1).

A in red indicates US weapon development that is going on. Dotted line indicates Enemy's development. Enemy started to develop their weapon later. But their development is targeted to realize higher functions in shorter time. US found out later that Enemy is developing a weapon with higher performance and it is expected to be realized earlier than US. To be competitive, US must develop a weapon with at least the same performance by the time Enemy realizes it. So US has to take the blue line instead of staying on the red.

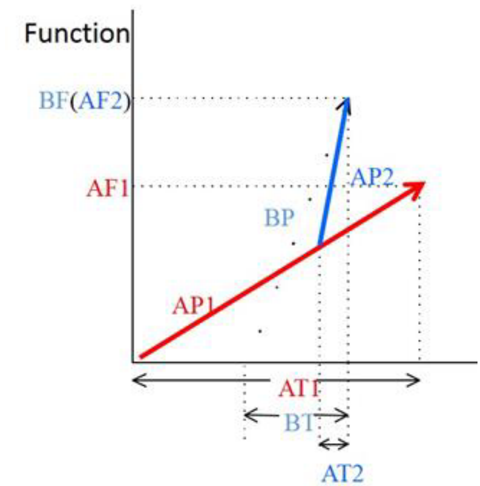

Figure 1. Early CE.

Industrial framework was linear and sequential at that time (Figure 2) and organizations were tree-structured (Figure 3) to maximize productivity, because a tree structure has only one output node so that it works best for this purpose.

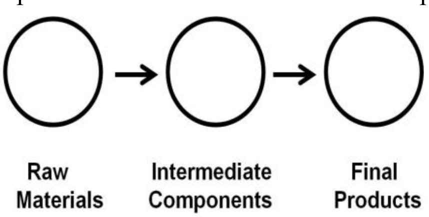

Figure 2. Linear and sequential processing.

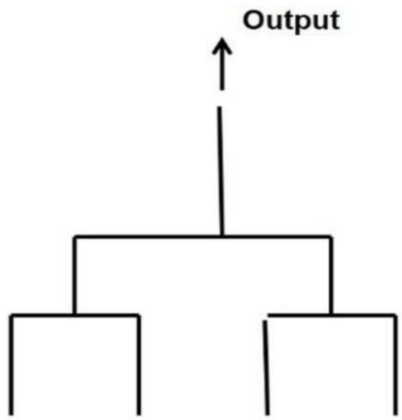

Figure 3. Tree structure.

To achieve their initial goal, such a structure worked effectively for US. But the situation changed. US had to catch up with Enemy. This drove them to introduce Concurrent Engineering (CE). CE brings downstream information upstream and processes them at the same time (concurrenly). Thus, they can reduce time. This idea was originally developed in computing to reduce running time. US applied this idea to weapon production. That is CE (Figure 4).

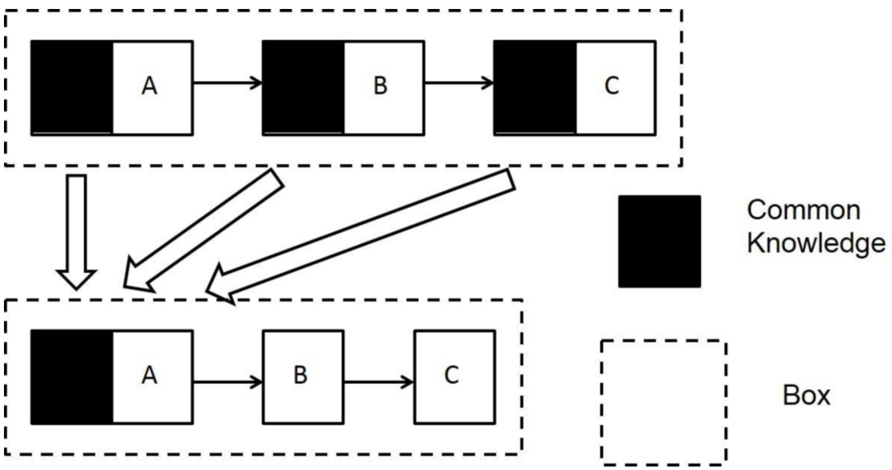

Figure 4. Concept of CE.

As private companies produced their products also in an open loop system and their organizations were tree-structured in those days, their goals were also to reduce time to market to increase market competitiveness. Therefore, CE spreaded very rapidly and extensively among private industries. And indeed it did reduce time to market remarkably.

2. Creeping diversification and personalization

Maslow [4] pointed out human needs start from material satisfaction and move up to mental satisfaction. And finally people want to actualize themselves (Figure 5).

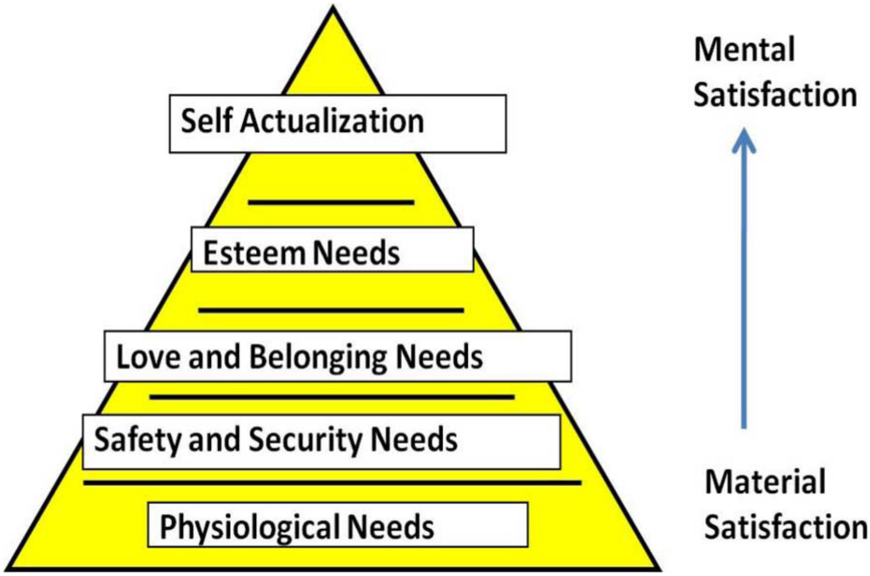

Figure 5. Maslow's hierarch of human needs.

As time went on, people wanted more and more to actualize themselves and the quickly progressing globalization which technological progress brought changed the world and people's requirements were quickly diversified and personalized.

When people wanted products, shorter time to market brought market competitiveness. But such a strategy was quickly losing effectiveness. So their next strategy was to provide a very wide variety of products. They thought customers would pick up what they want. But this strategy did not work so well, becausse people are wanting mental satisfction more than material satifaction. They would like to have their dreams come true. Biologists say that only humans can think about the future. It is the privilege of humans to dream [6].

Engineering is an activity to make our dreams come true. That is why humans are called Homo Faber (Man makes a tool). We take the trouble to make a tool to realize our dreams. Animals can use tools. But they pick up things from nature and use them as tools just for the immediate purposes. The current strategy of producing a wider variety is nothing other than regarding us as animals. Customers would like to make their dreams come true. Yesterday, they wanted material satisfaction. But now they are looking for mental satisfaction.

3. Creative customers

As people wanted products for a long time, we have been regarding them as consumers. But they are not passive consumers. They are very active and would like to customize our products.

Let us take children for example. They are very creative and invent many new ways of sliding down. Inventing new ways provides them with the same amount of, and often more satisfaction than sliding down in the usual manner. This is their challenge and challenge is another self actualization and it also satisfies their desires to learn to grow [5] (Figure 6).

Figure 6. Creative children.

Let us take another example. Young people introduce holes into their new jeans. As a product, those without holes are more valuable. Then, why do they do that? It is becausse they would like to share stories. Jeans are work clothes so if there are holes, they can create stories. This also comes from their human needs (Figure 7).

Figure 7. Creative young people.

4. Processes also yield values

Then how can we treat our customers not as animals, but as humans and satisfy them? Lego gives us a hint (Figure 8).

Figure 8. Lego.

Lego sells only blocks. But by combining them, we can realize many different things. They sell process values. They are not selling products. The processes provide people with the joy of self actualization. They enjoy the processes. They enjoy challenges. They enjoy learning to grow.

Lego reminds us of another computing approach, i.e., parallel processing. We have been focusing our attention only to final products and forgot all about the processes. We, engineers, have been thinking that products have value and it is most important how we can develop products with better performance. We forget completely to think about processes. Processes also yield values. Or more often, they create more values than products. We, engineers, have regarded processes just as cost increasing factor. Cost reduction was of paramount importance to engineers until now, so processes were just regarded from the standpoint of cost.Value is defined by the following equation.

$$Value = \frac{Performance}{Cost} \tag{1}$$

We have related processes only to the denominator, because we have interpreted performance as functions of a final product. But performance is not just functions. It includes processes, too. With the same musical instrument, we enjoy different musics. Thus the same product provides different performances. Thus, we should consider processes as numerator. Then, how can build up an industry framework which generates value from processes?.

5. Modularization

Before we consider this issue, let us take a look at the prevailing changes which are taking place in industry now. First, let us consider modularization. Modularization has been practiced since long time ago in engineering. Why it is spotlighted now is because it is considered a versatile and flexible way to respond to diversification and personalization. If we combine them differently, we can come up with many different products, just like Lego.

But most of modularizations used to be functional modularizations. But today emotional modularization is getting attention. Emotional modularization has been practiced for a long time in fashion industry. They modularize dresses, etc so that they can respond to personal preferences of customers. Now other industries are following suit. Daihatsu developed Copen. Its parts are changeable (Figure 9 and Fig.10).

Figure 9. Daihatsu Copen.

Figure 10. Changeable parts.

Currently, these parts are produced by experts and must be changed by experts. But remarkable progress of additive manufacturing, 3D printing [7], etc. will soon make it possible for customers to produce them by themselves. And if we change our design into this direction, customers will be able to change them as they like and whenever they like. So the day of car code is knocking the door.

6. Networked Society

Since Internet of Things (IoT) [8] and Cyber-Physical Systems (CPS) [9] were proposed, networking progressed rapidly not between human and human, but between product and product and between product and human. Recent proposal of Industries 4.0 [10] now connects industries.

Up to now, industries have been making efforts to be the best player. But as Knute Rockne, famous American football coach, pointed out,11 best does not necessarily builds the best team. Best 11 is the way to build up the best team. In fact, Rockne demonstrated this by changing University of Notre Dame to an invincible team.

So we have to say goodbye to producing a single best product, because products are now starting to work as a team. What is important for industries is how they can form a product team that works comfortably, flexibly and adaptively in response to the changing situations and contexts. What customers want now is not everlasting superior functions, but flexibility and fast adaptability to accommodate the frequent and extensive changes of today.

If the structure is a network, any node can be an output (Figure 11).

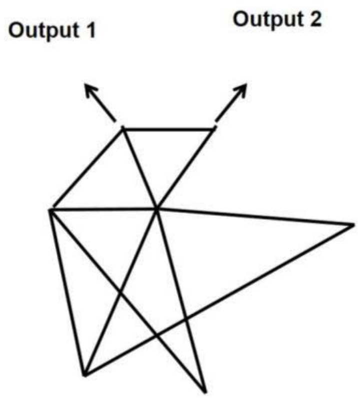

Figure 11. Network

Then, how can we change our industry framework into a network?

7. Parallel Engineering

As described above, CE originated from the idea of computer processing to reduce running time. But we have to remember that when computer scientists talked about concurrent processing, they also discussed parallel processing. How are they different?

Let us consider from engineering viewpoint. Concurrent processing focuses attention to the final result. If processing is sequential, it takes time. So by introducing concurrency, running time can be reduced. But the focus is on the final result.

But if we change our eyes from one single job to the whole jobs, then we can process many jobs at the same time, because they do not have to be sequential. We can process any job, if that processor is idle. Then, what happens if we change our focus from the final product to parts? Different parts do not have to be developed sequentially. In fact, most final product companies are assemblers of these parts or components.

Then, what happens if we build up an industry framework where parts suppliers play the central role? This is just what parallel processing in computing is doing. Such parts- supplier-centric industry framework can lead to such a network as shown in Figure 12.

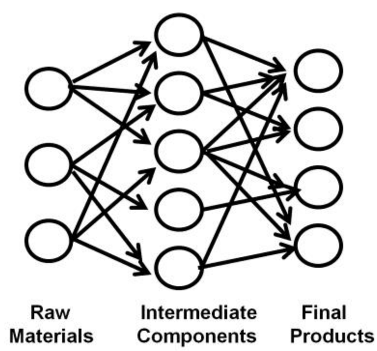

Figure 12. Parallel Engineering industry framework.

It must also be emphasized that the new emerging material engineering enables us to realize such a framework. Although the progress of material engineering has been remarkable, it has been difficult to develop materials, which possess many different attributes customers desire. So engineers had no other choice but to select among what were offered. But such new technologies as additive manufacturing, etc. now enable us to develop materials with any attributes customers desire.

In this framework, parts suppliers do not have be just suppliers to a final product company. They could produce parts which are very versatile and widely applicable. These parts are, so to speak, engineering Lego blocks. So they can be used in wide applications. Thus, parts companies can explore their own markets. In fact, this networked framework will generate a myriad of combinations. They do not have to keep eyes on final product companies any more. Parts companie will play the crucial and central role in developing markets.

This is just the same as what is happening now in soccer. In soccer, forward players were most important yesterday. But today midfielders are increasing their importance. They can see how situations change. They see most of the game. Forward players are focusing their attention to the goal. Why did such a change happen in soccer? It is because the situations change very frequently and extensively in today's soccer. Thus, in the next industry framework, parts companies will lead the whole industry.

The role of final product companies will change dramatically. They will still remain assemblers. But their products changes widely from time to time to respond to the widely changing requirements from customers. They combine many different parts and assemble them to realize what customers want. Their roles will change and tlhey will become important more as service providers and consultants.

And we have to remember that even customers themselves can be combiners/assemblers. Just like Lego, they can buy parts or components and enjoy the work. We should learn from fashion industries. They produce many different clothes, etc. but as dress code indicates, we dress up to suit to the situations and contexts. And we also should mention accessaries. We enjoy how we can combine them. Such different combinations create changes. We have to remember change is another human need. It should also be added that this new network of industry framework is nothing other than a neural network. So it also satisfies our desire to learn to grow.

8. Summary

Recently, industrial environments changed greatly. Yesterday, efficiency was most important. The goal was clear and industries were expected to produce products with better performance in shorter time. But today rapidly progressing diversification and personalization call for flexibility and fast adaptability.

Concurrent Engineering worked very well yesterday. But to adapt to the new environments, industry has to adopt a new framework. Concurrent Engineering worked very well, because it brought downstream jobs upstream and reduced time in sequential production. But changes are taking place frequently and extensively these day and our society is moving rapidly toward more diversification and personalization. So instead of a sequential framework, a network framework must be developed.

Parallel Engineering is proposed here to accommodate such changes and needs. It processes many jobs simultaneously. In this new framework, diversified and personalized requirements can be answered by combining different parts or components. Thus, the role of parts companies will become increasingly important and traditional final product companies will become combiners and their roles will change to service providers. As a myriad of combinations is possible, there will be many new markets and we can meet customers' preferences and needs more adequately.

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Assessing Producibility of Product Platforms Using Set-Based Concurrent Engineering

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Abstract. This paper presents a method to facilitate model-based producibility assessments of product variants in the early phases of platform development. The approach uses set-based concurrent engineering principles to explore and narrow down a design space towards feasible alternatives. A case including *tool accessibility* and *assembly robustness* of an aerospace sub-system platform is used to demonstrate the approach. The assessment activities can be prepared in parallel, and support the concurrency needed, across design and manufacturing, to serve improved process efficiency. Ultimately, the approach may reduce late design modifications thanks to increased reuse of manufacturing knowledge, as well as reduce cost thanks to less physical prototyping and testing.

Keywords. integrated platform development, product platforms, manufacturing platforms, producibility assessments, set-based concurrent engineering

Introduction

Research on platforms typically aim to understand how scale benefits in production can be met, using a low number of manufactured parts [1]. However, the industrial need and the direction of research points at increased support for reuse in the development phases [2]. A prevailing concern for such a course is the risk of overlooking manufacturing aspects. In the pursuit for a feasible producible product family, there is a need to reduce time-consuming and costly physical verification and better assess the producibility of the platform, and the family of variants derived from it. In the same way as product concepts can be explored, production concepts can be explored simultaneously. In light of this concurrency, producibility refers to the relative effort needed to produce products with respect to available technology.

Computer Aided Engineering (CAE) tools can be used to simulate product performance, such as product life, as well as manufacturing capabilities, such as welding quality. Simulations are typically used for product performance verification, process planning and pre-production verification. In these late phases of the development, a design modification is more expensive compared to that of the conceptual phases of development. Being able to better assess multiple producibility

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aspects on multiple design alternatives, and to assess them in concurrency can provide the efficiency needed to support design engineers in making cross-discipline design decisions [3]. In this way, a product family can be fit for desired manufacturing conditions early in the development and costly design modifications in the late phases of development can be reduced.

1. Research Approach

This paper introduces means to prepare platform assessment processes using improved process activities. Such platform assessment process can be used to assess producibility of product platform concepts. To illustrate the approach, a case from the aerospace industry is provided. The case is prepared as a part of a long running collaboration with GKN Aerospace Sweden AB. The purpose of using a real-life case is to validate the research in an industrial context and provide rigor to the research findings. By interviewing system specialists and examining relevant documentation, such as design guidelines and process descriptions, in-depth knowledge of products, manufacturing tools and equipment as well as process knowledge have been extracted. During workshops, system specialists and researchers have revised and refined models in collaboration. To propel the research provided in this paper, a research question is formulated: *how can producibility be assessed across the design space of a conceptual product platform?*

2. State-of-the-art

This section presents a body of research related to platform development of both products and manufacturing systems. It also gives an overview of producibility related to product and production development and how set-based concurrent engineering relates to platform development.

2.1. Product Platforms

Product platforms as a means of reusing design knowledge has been receiving significant attention over the past decade [1]. The corporate view of a product platform is a collection of physical parts that can be combined into distinctive products [4]. These physical parts, or modules, are created with a static set of customer requirements in mind. However, this view on platforms is sub-optimal for businesses where customers constantly demand new functionality, or where changes to the product are commonplace due to introduction of new requirements [5]. In brief, such platforms support a low number of parts in manufacturing, but provides little support in development [6]. To increase support in the development phases, there are other ways to maintain efficiency over time. For example, design reuse could encompass other things than physical parts. Alblas and Wortmann [7] suggest design reuse using function platforms. Function platforms enable reuse of functions as well as the configuration of a function family, rather than a part family. Levandowski et al. [8] propose using function modeling as a way to describe product platforms in the early phases of development to increase the ability to reuse.

2.2. Producibility of Product Platforms

There are several approaches to integrate manufacturing in design, such as Design for Manufacturing (DfM) and Design for Assembly (DfA). These approaches provide design engineers with guidelines on how to design products to be producible. Producibility links the functions, characteristics and performance of products together [9]. There are several examples of producibility aspects, such as tool accessibility in an assembly process and geometrical robustness [10]. However, producibility of product variants has received little attention, although some work has recognized the potential to integrate manufacturing platforms and product platforms. Such integration is discussed by Michaelis [11], among others. Michaelis describes how co-development of products and manufacturing systems can be accomplished using an integrated platform approach. As function models can represent designs, also manufacturing systems may be modeled in a similar fashion. By using manufacturing operations as connecting elements, the two disciplines can be linked [11]. Closely related to product and manufacturing platforms, Koren et al. [12] suggest reconfigurable manufacturing systems that can accommodate several product variants.

2.3. A Platform Model

To efficiently support design reuse in the development phases, platform models need to allow for modeling of both products and manufacturing systems during all phases of the platform development process. Claesson [13] developed the configurable component (CC) concept – a product platform model that was later extended to include manufacturing systems and manufacturing operations [11]. The model supports reuse of functional features, which is made possible through an object-oriented approach based on enhanced function-means (EF-M) modeling [14]. Variability is served through alternative design solutions, *the modular bandwidth*, and parametric ranges, *the scalable bandwidth*.

A platform based on the CC concept consists of a set of generic systems, each system described by one CC object. A CC object can describe for example an entire aircraft, a jet engine or welding equipment. Essentially, an architecture of CC objects does not represent merely one variant, rather every engine in the product platform or all welding equipment in the manufacturing platform. Thanks to the generic representation of the CC concept, compared to other platform approaches, the platform does not have to rely on fixed interfaces between systems to achieve concurrency. Instead, the interfaces between objects can be configured simultaneously, which leaves the design to be more flexible for longer time in the development.

There are several objects within a CC. The *DNA* of the CC, the design rationale (DR), describes a decomposition of the design and how each element of the CC fulfills a function. The DR is manifested as an EF-M tree, consisting of functional requirement objects (FRs), design solution objects (DSs) and constraint objects (Cs) [14]. Each object has a parameter set of variant parameters (VPs). The VPs define in what dimensions the CC object can vary, thus the ranges of the VPs determine the bandwidth of a CC object. The parameter set also provides information of how the parameters are distributed to the objects within the CC. To receive variant parameters (VPs) from other CCs, the control interface (CI) object is used. And to expose the VPs to other CCs, the composition set (CS) object is used. By assigning values to the VPs, a CC object can be configured into distinctive variants. The CC object is illustrated in Figure 1.

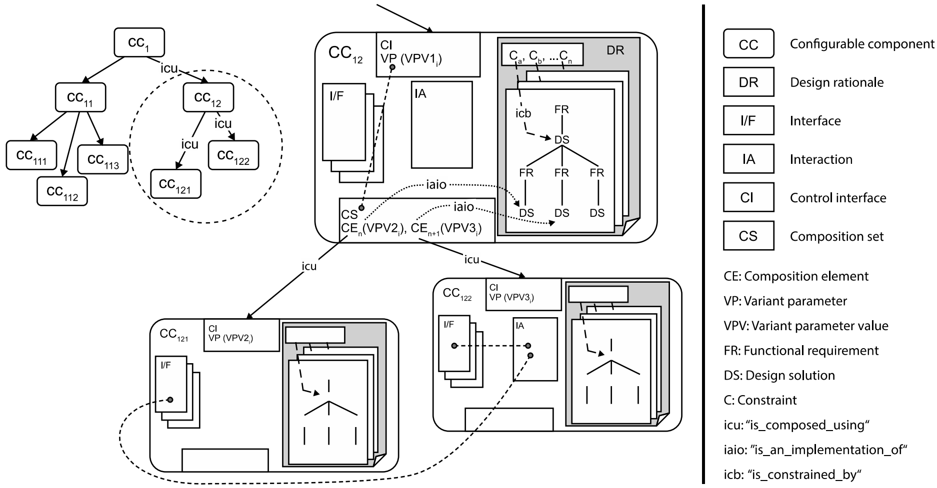


Figure 1. A configurable component, CC object (as drawn in [11], adapted from [13]).

2.4. Set-based Concurrent Engineering

Concurrent Engineering (CE) is a systematic approach to transdisciplinary development of products, manufacturing systems and supporting processes. CE is mainly seen as an organizational approach where processes can be made in concurrency, however they can also be reflected in how designs are modeled [6]. CE primarily emphasizes the early interchange of information that affect downstream activities, when the information is still preliminary [15].

In the early phases of development, contrary to point-based design, set-based advocates design space exploration, rather than selecting an arbitrary solution. Set-based concurrent engineering (SBCE) builds on three principles, 1) *mapping the design space*, 2) *integrating by intersection*, and 3) *establishing feasibility before commitment*. These principles advocate a sound depiction of a design and how it may vary due to changing functionality and requirements. Sobek et al. [16] summarize SBCE as *"reasoning, developing and communicating about sets of solutions in parallel and relatively independently."* SBCE can be applied to explore a wide variety of design alternatives that are systematically narrowed down by excluding inferior alternatives.

3. The Suggested Approach

In the early phases of development, it is inexpensive to explore the design space, test alternative solutions and consecutively eliminate unfeasible alternatives to find feasible product variants. However, to generate sufficient information about a set of design alternatives, an assessment process needs to be prepared. Thereto, suitable software systems must be chosen, and a PLM architecture to be established. In this case, such a PLM architecture revolves around a platform modeling and configuration tool, including platform models, to which CAE tools are linked and arranged to. A method to support design engineers in preparing such platform assessment processes is proposed.

3.1. Platform Assessment Process Blocks

To sufficiently prepare a platform assessment process, a standalone assessment process block is introduced. The process block builds on set-based concurrent engineering, to allow for exploring the design space as well as consecutively excluding inferior alternatives as new information becomes available. Preparing an assessment process block includes five steps. The steps are illustrated in Figure 2 and described below:

1) Define a trade-off parameter, to determine what to assess
2) Update the platform with design and manufacturing information, to allow for design reuse of functions, solutions and constraints. More details on this step is provided in [6,11]
3) Create or update parameterized conceptual 3D models using suitable software, to form a basis for more detailed visualization and simulations
4) Create or update a simulation model using an appropriate CAE software, to be able to generate new information about a set of conceptual design alternatives
5) Assign specific constraints, from the platform, onto the assessment process block, to exclude inferior alternatives as information becomes available

When several process blocks have been prepared, they can be arranged into a process to gain an aggregated and sound output as a basis for design decisions. The output of a platform assessment process is either no feasible alternatives, or a number of feasible alternatives. The former scenario leaves the design engineer with information of why there are no feasible alternatives. The latter scenario leaves the design engineer with trade-off information as a basis for comparison between a set of conceptual design alternatives. A platform assessment process with several process blocks is illustrated in Figure 3. An essential part of arranging the process blocks into a complete process is to ensure the information flow between the software systems, which is why a PLM architecture may be prepared to satisfy the need to interchange information between the software interfaces. An example of how to prepare such a PLM architecture that supports the platform assessment process blocks is provided in [3].

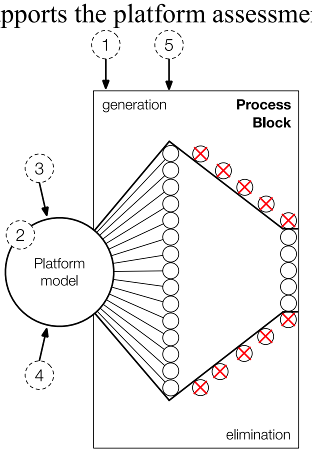


Figure 2. A platform assessment process block.

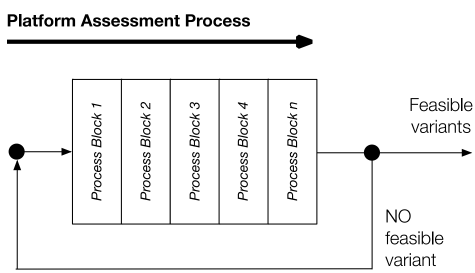


Figure 3. A platform assessment process .

4. Illustrative Case

The approach is illustrated using a case from the aerospace industry. The case company, GKN Aerospace Sweden AB, is a component supplier that designs and manufactures static parts for commercial jet engines. The studied product, Turbine Rear Structure (TRS), is located at the rear of the engine and is illustrated in Figure 4 and Figure 5. Each TRS is currently manufactured at a yearly volume of a few hundred units and is customized for different customers. The case company has the ambition to reduce the time from a customer request to an offer of feasible conceptual alternatives from three months to three weeks. To be equipped for such a scenario, an imminent concern is to incorporate knowledge about manufacturing in the platform concept development.

The TRS can be manufactured in various ways. This case illustrates a welding assembly scenario, which is why the TRS is divided into segments, shown in Figure 5. A new requirement is introduced. The engine need to endure higher operating temperatures. As a result of the new requirement, the thermal loads in the TRS will increase. To reduce the increased thermal loads, a solution is to lean the mid-section, shown in Figure 5. A set of lean angles is studied to find a feasible solution, and the producibility is concurrency explored across the design space.

To ensure producibility, *tool accessibility* and *assembly robustness* are assessed for the design alternatives encompassed by the platform, each with a discrete lean angle of the mid-section.

- *Tool accessibility*: There is a risk of machine disturbances due to collisions between the welding tool and work pieces, and the effects of the weld process when the pieces are welded together. Preliminary models of the TRS and weld characteristics are created to explore different accessibility alternatives.
- *Assembly robustness*: The position of the weld split line is critical for the assembly robustness. A simulation model is created to explore alternative positions of weld split lines, as the robustness of the different alternatives can be assessed.

A platform assessment process comprising of two assessment process blocks is prepared. The first process block concerns tool accessibility. The second process block concerns assembly robustness.

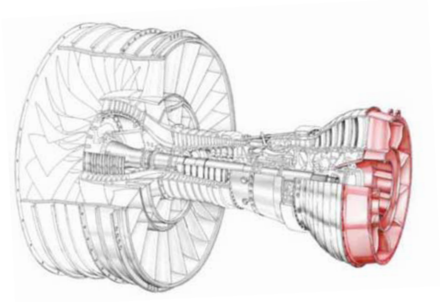


Figure 4. An aero engine with the TRS to the right [17].

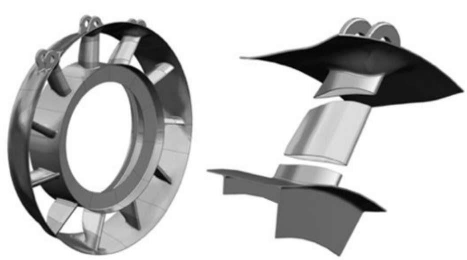


Figure 5. The TRS divided into segments, which are welded together in an assembly process.

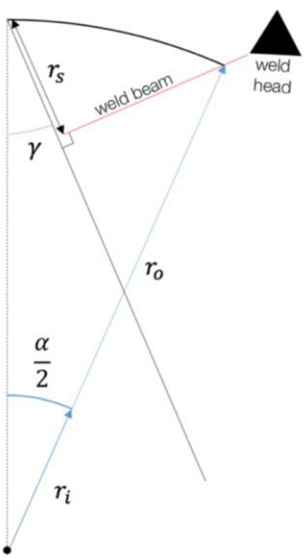
4.1. Process Block 1 – Assessment of Accessibility

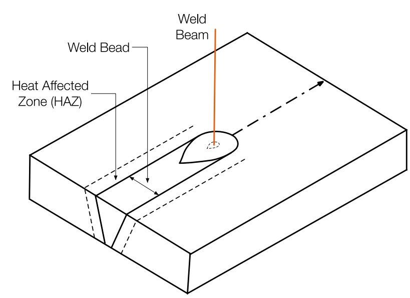
A trade-off parameter is defined: *tool accessibility* (binary measure: OK/NOTOK). In this case, the interaction between the weld beam and the TRS segment is analyzed. The case is represented by a model describing the relationship between design features and manufacturing knowledge. To better assess tool accessibility of a number of conceptual design alternatives, design principles and manufacturing knowledge are modeled in the platform system objects, provided in Figure 1, to be reused across the bandwidth of the platform.

The variant parameter (VP) r_s, shown in Figure 6, defines the constraining upper limit of the weld split line, to ensure that the weld beam will not interfere the with the outer ring of the TRS design. The same procedure is made for the inner ring. In this way a limiting area for the weld split line can be efficiently derived for each alternative across the design space. Through this, accessibility can be ensured.

By integrating the design and manufacturing solution spaces, the weld bead and the Heat Affected Zone (HAZ) are constraining the area for where the weld split lines are to be positioned to ensure accessibility. To ensure the quality of the welded product, the weld bead and the *HAZ* are not allowed to interfere with surrounding geometry, the weld beam shall be undisturbed until it meets the work pieces and the weld beam shall be perpendicular to the weld split line, see Figure 6 and Figure 7.

An integrated platform is prepared with the information provided above using the platform development software Configurable Component Modeler (CCM). CCM is an object-oriented modeling software which is based on the theory of EF-M modeling and the configurable component concept. By modeling a bandwidth of the VP *lean angle*, γ, a number of design alternatives is generated using CCM. The *outer radius*, r_o, the *inner radius*, r_i, and the *number of segments*, N, were held constant for pedagogical reasons. The results are provided in Table 1.





r_O – *radius* of the outer ring
r_i – *radius* of the inner ring
N– *number of segments* in a full ring
α – *angle* that defines the segments $\alpha = \left(\frac{360}{N}\right)$
γ – *lean angle* of the middle segment
r_s – *constraining distance* for weld beam

$$r_s = r_o\left(cos(\gamma) - cos\left(\gamma + \frac{\alpha}{2}\right)\right)$$

Figure 6. To the left; a preliminary 2D model a TRS segment, in the bottom right; the relationships between the VPs of the preliminary 2D model, and in the top right; a schematic model of a weld beam in interaction with work pieces with welding characteristics.

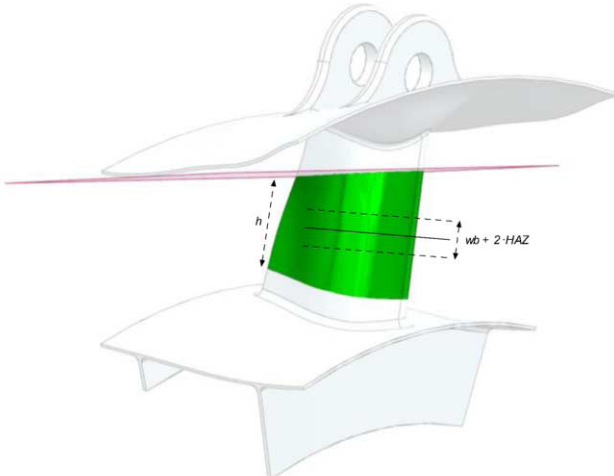


Figure 7. A preliminary 3D model of a TRS segment, depicting the constraining VPs for determining the welding accessibility.

Table 1. A binary measure of accessibility (OK/NOTOK) can be generated based on the preliminary information.

Variant [number]	**Outer Radius,** r_O / **Inner Radius,** r_i [mm]	**Lean Angle,** γ [°]	**Weld Area Height,** h [mm]	**Manufacturing constraint** [mm] $h < wb + 2 \cdot HAZ$	**Accessibility** [OK/NOTOK]
1	680 / 450	0	107	h > 70; OK; NOTOK	OK
2	680 / 450	1	104	h > 70; OK; NOTOK	OK
3	680 / 450	2	101	h > 70; OK; NOTOK	OK
4	680 / 450	3	98	h > 70; OK; NOTOK	OK
5	680 / 450	4	95	h > 70; OK; NOTOK	OK
6	680 / 450	5	92	h > 70; OK; NOTOK	OK
7	680 / 450	6	89	h > 70; OK; NOTOK	OK
8	680 / 450	7	86	h > 70; OK; NOTOK	OK
9	680 / 450	8	83	h > 70; OK; NOTOK	OK
10	680 / 450	9	80	h > 70; OK; NOTOK	OK
11	680 / 450	10	77	h > 70; OK; NOTOK	OK
12	680 / 450	11	74	h > 70; OK; NOTOK	OK
13	680 / 450	12	71	h > 70; OK; NOTOK	OK
14	680 / 450	13	68	h > 70; OK; NOTOK	NOTOK
15	680 / 450	14	65	h > 70; OK; NOTOK	NOTOK
16	680 / 450	15	62	h > 70; OK; NOTOK	NOTOK
17	680 / 450	16	60	h > 70; OK; NOTOK	NOTOK
18	680 / 450	17	57	h > 70; OK; NOTOK	NOTOK
19	680 / 450	18	54	h > 70; OK; NOTOK	NOTOK
20	680 / 450	19	51	h > 70; OK; NOTOK	NOTOK

4.2. Process Block 2 – Assessment of Assembly Robustness

A 3D geometry of the TRS segment, and the preliminary verification of accessibility is the output from *Process Block 1*, and the input to *Process Block 2*.

A trade-off parameter is defined: *assembly robustness* (binary measure: OK/NOTOK). The platform model is updated with a constraint, in this case a sensitivity measure RMS (Root Mean Square). Thereafter, a simulation model is created in a CAE software tool (RD&T). By applying the process block, a set of weld split lines and the sensitivity measure (RMS) for each weld split line can be generated. The less sensitive the alternative (low RMS value), the more robust the assembly. Two alternative weld split lines are provided and can be seen in Figure 8. More details on how to prepare this simulation model is provided in [10]. The lowest tolerated RMS is modeled in the platform and is assigned to *Process Block 2* to exclude inferior weld split lines as the simulation is executed.

The result of the simulation is provided in Table 2 can be made for all the conceptual alternatives provided in Table 1. In this way, it is possible to further explore the producibility across the design space, within the tool accessibility constraints provided in *Process Block 1*.

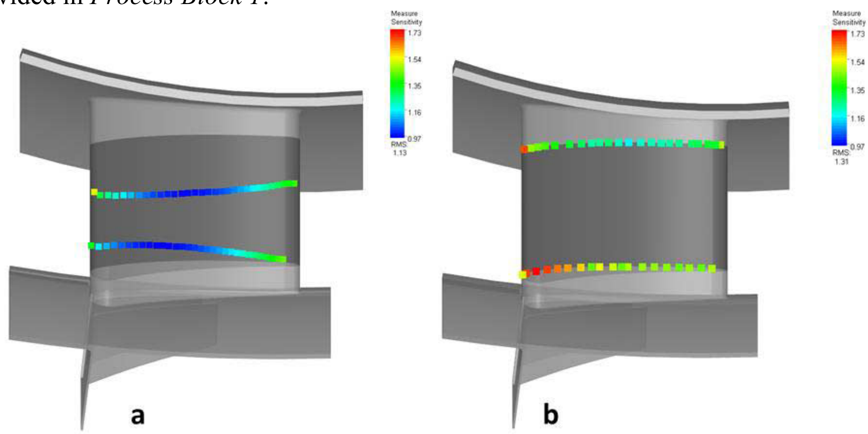


Figure 8. Two different alternatives of weld split lines (a and b), and their welding robustness [10].

Table 2. Binary measure of assembly robustness (OK/NOTOK), generated based on simulations

Variant [number]	**Accessibility** [OK/NOTOK]	**Sensitivity,** *RMS* [RMS]	**Sensitivity Constraint** [RMS]	**Assembly Robustness** [OK/NOTOK]
4	OK	1,13	$RMS < 1{,}2$; OK; NOTOK	OK
4	OK	1,31	$RMS < 1{,}2$; OK; NOTOK	NOTOK

5. Conclusion

This paper describes a method to prepare platform producibility assessments supporting set-based concurrent engineering. An aerospace sub-system in a welding assembly is provided to illustrate the approach. Two producibility aspects are studied – tool accessibility and assembly robustness.

To accomplish increased process efficiency in platform development, the integration between design and manufacturing must be improved. The use of an integrated platform supports the manufacturing providence needed to prepare producibility assessments across a design space. The assessment process blocks provided in this paper can be prepared in parallel and be arranged to find producible design alternatives within the platform bandwidth. The order of the process blocks needs to conform with the input and output of the activities. However, the order of the process blocks may have an impact on the size of the design space. This is a matter of future work.

The improved integration of manufacturing in platform development may facilitate early model-based producibility assessments of platform concepts. By using the suggested assessment process blocks in making producibility assessments of platform concepts the need for late design modifications and costly physical prototyping and testing can be reduced.

Acknowledgements

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Towards a Comparative Analysis of Interoperability Assessment Approaches for Collaborative Enterprise Systems

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Abstract. Challenges such as globalization and novel technologies are changes-drivers that require transformation within enterprises and their environments. To handle that, enterprises are progressively collaborating with others and becoming part of a Networked Enterprises (NE). In this collaborative and transdisciplinary context, one of the difficulties faced by companies willing to work together, are the interoperability problems between their systems. In order to avoid these problems and consequently, take corrective actions on time, enterprises need to predict and solve potential problems before they occur. To deal with that, evaluations can be performed to assess interoperability and therefore identify strengths and weaknesses of the considered enterprise systems. Despite, numerous interoperability assessment methods existing in the literature, many of them address only one interoperability aspect. In addition, they can also use different approaches and metrics to perform the interoperability evaluation. Thus, it can be difficult when enterprises have to deal with multiple interoperability aspects within a NE. Hence, the objective of this paper is to propose an analysis of the main relevant evaluation methods regarding interoperability. The proposed analysis is essential and will serve as a first step towards proposing a new approach for assessing enterprise systems interoperability within a NE..

Keywords. Networked Enterprise, Transdisciplinary, Collaborative Enterprise System Interoperability, Interoperability Assessment

Introduction

Nowadays, the dynamics of the socio-economic environment leads enterprises to face a variety of challenges such as globalization, new technologies, financial crisis, new markets, etc. These challenges are change-drivers that require transformation within enterprises and their environments [1]. To deal with that, enterprises are progressively shifting their boundaries and collaborating with other companies and participating in a so-called Networked Enterprise (NE) [2]. The companies that compose a NE can have different sizes (e.g. small, medium and large enterprises), they can be geographically distributed (e.g. collaborations between regional, national and international enterprises), and also can be field-specific enterprises (e.g. a NE composed by only marketing agencies) or transdisciplinary enterprises [3] (e.g. collaboration among

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different disciplines such as marketing, production engineering, financial, healthcare, etc.). Considering this collaborative and transdisciplinary context, i.e. NE context, and based on [3], [4], [5], [6], [7], we argue that one of the difficulties enterprises may face, regarding effective collaboration, is the development of interoperability among their collaborative enterprise systems (CESs). The term CESs, in this paper, represents the enterprise systems that collaborate with systems from other enterprises within the NE. In light of this, the Networked Enterprise meta-MOdel (NEMO) [2] has been proposed to address the importance of the interoperability within a NE, describing it as a crucial requirement that needs to be verified when starting a new collaboration [8], [9]. As soon as this requirement is not achieved, interoperability becomes a problem that must be solved [10]. Interoperability problems are mainly related to incompatibilities that obstruct the sharing and exchanging of any kind of information, but mainly contextual information, between CESs [11]. To deal with this kind of problem, specific evaluations can be performed to have a clear view about strengths and weaknesses of the considered NE in terms of interoperability, at an early stage [2]. Numerous methods and approaches have been proposed in the literature regarding interoperability assessment [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]. Some surveys can be found in [7], [25] and [26]. Among these methods and approaches, three kinds of interoperability measurements can be identified [16], [27]: the measurement performed (1) before the interoperation starts and when partners are unknown; (2) before the interoperation starts and when partners are known; and (3) during the interoperation between two known partners. This latter measurement is out of scope of this paper, because it is performed only during interoperation, meaning that it is too late to identify interoperability problems at this stage. To our best knowledge, despite the variety of these evaluation methods, none addresses both (1) and (2) types of measurements at the same time, considering all interoperability aspect [11]. Therefore, identifying interoperability aspects to be assessed, and the related key features is mandatory to support the NE interoperability development, including the detection and prediction of problems at early stage. Thus, the following questions are raised: “How can we assess the interoperability of CESs within a collaborative and transdisciplinary context, when dealing with different interoperability aspects?” and “Which method(s) is (are) to be chosen in this context?”

The objective of this paper is to propose a comparative analysis of the main relevant evaluation methods regarding interoperability. This needs, first of all to identify evaluation criteria to be taken into account, considering the related works and the context of our research. The proposed analysis is essential and will serve as a first step towards proposing a new approach for assessing CESs interoperability within a NE.

The rest of the scientific paper is organised as follow – Section 1 presents the relevant related works on interoperability within a NE. Section 2 shows the analysis of interoperability evaluation methods. Also in this section the findings are discussed and some perspectives highlighted. The conclusion and future work are brought forward in Section 3.

1. Related work

This section gives an overview of the NEMO meta-model. highlighting the core concepts of NE and interoperability, as well as, relationships between them. This overview leads to identify the main properties that need to be considered when assessing interoperability. Thereafter, related works on interoperability assessment are presented.Second paragraph.

1.1. NEMO: Networked Enterprise Meta-Model

NEMO [2] aims at providing a common understanding of the NE and interoperability concepts, based on a systemic approach. It defines a NE as: “a system composed of at least two autonomous systems (enterprises) that collaborate during a period of time to reach a shared objective”. This meta-model considers two views of interoperability: as a requirement that needs to be met when at least two systems are willing to collaborate together and as a problem when this requirement is not fulfilled. Figure1 gives a simplified view of NEMO and its main elements. More details can be found in [2].

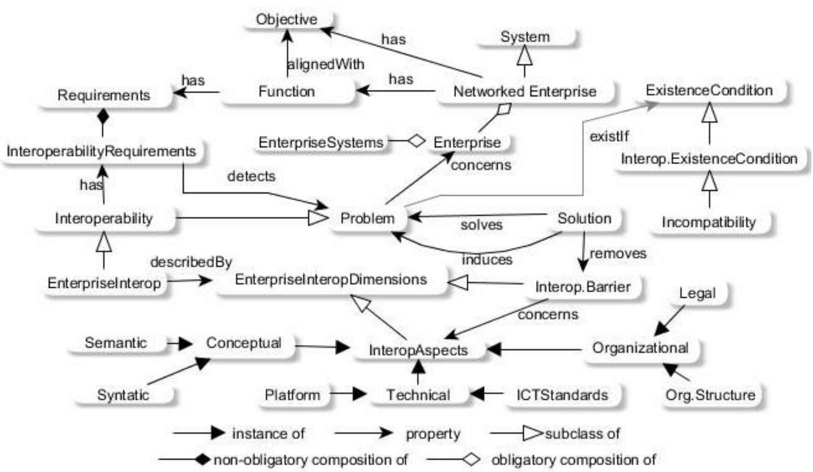

Figure 1. Simplified view of NEMO elements [2].

In order to better describe the interoperability concept and its elements within a NE, NEMO is based on the interoperability dimensions, previously defined by the Ontology of Enterprise Interoperability [10] and the Framework for Enterprise Interoperability [11]. Here, we present the two most important concepts that will be considered in the analysis of section 3. The first one is the interoperability aspects which describes the different facets of interoperability. The second concept is interoperability barriers representing the related problems. The considered interoperability aspects and related barriers are: 1) Conceptual interoperability deals especially with knowledge and information sharing among CESs [28]. Hence, Conceptual barriers are concerned with the syntactic and semantic incompatibilities of information to be exchanged between CESs [11]. 2) Technical interoperability covers the technical issues of linking computer systems and services. [28]. Thus, the Technical barriers are concerned with the lack of compatible ICT platforms and standards allowing the use of heterogeneous computing techniques for sharing and exchanging information between two or more CESs [11]. 3) The Organizational interoperability deals with bringing collaboration capabilities to enterprises that wish to exchange information and may have different internal structures and processes [28]. Compliance to legislation [28], [29] is also considered in this context. Consequently, Organizational barriers are concerned with the incompatibilities of organisation structure, management techniques and legal issues implemented in two or more enterprises [11]. It is worth noting that interoperability is a not-bidirectional property [21]. Given two entities A and B and measuring their interoperability level I(x,y) it is structurally coherent to find $I(A,B) \neq I(B,A)$. This structural property doesn' t impact the evaluated methods because of its internal feature but it explains the behavioural aspects of the approached property concepts.

1.2. Related works on Interoperability assessment

To support enterprise members of a NE to better interoperate, the interoperability between their CESs requires being assessed and continuously improved [16]. According to [16] interoperability assessment methods can be classified based on four properties; (a) the type of interoperability assessment, which are Levelling (defining a basic set of interoperability maturity levels that CESs can achieve) or Non-levelling (not using the maturity model approach). (b) The used measure, which are Qualitative (Subjective methods defined by the general criteria of the CESs evaluation) or Quantitative (Methods that define numeric values to characterise the interoperations between CESs). (c) The used approach, which are Black Box (Methods considering mainly the analysis of the CESs inputs and outputs without worrying about their properties and interactions) or White Box (Methods where the concept for which input–output mappings, the transformation structure as well as the state of the CESs are known). (d) The application context, which can be a priori or a posteriori. The a priori context uses the potentiality measurement which relates to the potential of a CES to be interoperable with a possible future partner whose identity is not known at the moment of evaluation. The a posteriori application context uses two measures: (i) the compatibility measurement is done concerning the identified barriers to interoperability. This measure can only be performed when the two CESs of the interoperation are known. (ii) The performance measurement is to be done during the test or operation phase of two interoperating CESs. As asserted in the introduction, this latter type of measurement is not considered in this paper. Although, it is worth noting that this kind of measurement is relevant when the enterprises want to validate their potential measures i.e. to verify if the potential measures are aligned and coherent with the real ones. The next section introduces the existing methods and approaches that deal with the interoperability assessment.

1.3. Overview on Interoperability Assessment Methods

A variety of assessment methods can be found in the literature. Many of them are defining a maturity model which consists in a framework that describes, for a specific area of interest, a number of levels of sophistication at which activities in this area can be carried out [30]. The main existing interoperability maturity models are the Levels of Information System Interoperability (LISI) maturity model [12], the Organisational Interoperability Maturity Model (OIMM) [13], the Levels of Conceptual Interoperability Model (LCIM) [14], the Enterprise Interoperability Maturity Model (EIMM) [15] and the Maturity Model for Enterprise Interoperability (MMEI) [16].

Besides these maturity models, we have identified other methods such as: the GRAI Grid [17], the European Telecommunication Standards Institute (ETSI) method [18], the layered interoperability score (i-Score) [19], the Enterprise Interoperability Degree Measurement (EIDM) compatibility matrix [20], the Yahia et al. [21] approach based on semantic blocks [22] and some ICT standard validation methods [23], [24].

In the next section we aim at analysing the evaluation methods, taking into account all the properties and interoperability aspects identified on the previous sections.

2. Analysis of interoperability assessment methods

The objective of this section is not to provide an exhaustive review of existing assessment methods, but rather it is to present relevant methods that are selected specifically for the purpose of the analysis. The analysis considers some of the already reviewed methods in [7], [25], [26], as well as other and more recent evaluation methods. We intend to identify how these evaluation methods are performing interoperability assessment in CESs. This will allow us to verify if these methods address both considered types of measurement (i.e. before and after knowing interoperation partner(s)) and their coverage in terms of interoperability aspects. First, we identify the evaluation criteria and the evaluation methods to be analysed. Furthermore, the analysis considering the identified criteria and methods is performed. Based on that, findings and perspectives are discussed at the end of this section.

2.1. Criteria identification

The criteria identified in this section are based on the interoperability assessment domain. The following criteria were chosen because they often appear when describing an interoperability evaluation method. The first considered criterion is the interoperability aspect. This criterion is related to the interoperability level(s) addressed by the evaluation method(s), i.e. conceptual, technical or/and organisational interoperability. The second criterion is based on the method properties described in section 1.2. It regards the type of interoperability assessment (in this paper we will call it as structure property), the used measures, the used approach and the type of interoperability measurements. Considering the structure property, a method can be a Levelling or a Non-levelling method. Taking into account the used measure property, a method can be described as a Qualitative or a Quantitative method. Considering the used approach property, methods can be described as Black Box or White Box methods. For the last property, we will call it “type of interoperability measurement” instead of “application context”. Thus, we will identify which type of measurement the methods adopt rather than classify as a priori or a posteriori. The two considered type are: (1) the measurement before any interoperation starts and the partner(s) is (are) unknown; (2) before any interoperation stars and partner(s) is (are) are known.

2.2. Selected evaluation methods

The LISI maturity model [12], OIMM [13] and LCIM [14] are chosen because they cover the technical, organisational and conceptual interoperability aspects respectively. The EIMM [15] is included in this analysis because it brings forward the enterprise domain, focusing mainly on the organisational aspect. MMEI [16] is selected because it is based on the previous maturity models and covers all aspects of interoperability. Beside these maturity models, we also include the GRAI Grid [17] that identify organisational incompatibilities. Furthermore, the ETSI method [18] and the ICT standards validation methods such as [23], [24] are also included in the analysis because they deal mainly with the technical interoperability evaluation. Finally, the i-Score [19], the EIDM compatibility matrix [20] and the Yahia et al. approach [21] are included in this analysis because they are quantitative methods.

2.3. Analysis considering the Interoperability aspects

The LISI maturity model covers only the technical interoperability between CESs. Considering its limitations, LISI was extended by OIMM and LCIM to cover the organisational and conceptual aspects respectively. LCIM intend to link the technical and conceptual CESs design. EIMM deals with enterprise modelling assessments, which mainly concerns organisational and conceptual interoperability aspects. It focuses on the use of CES models and the maturity of their usage, which requires a correct syntactic and semantic representation [15]. Among the reviewed levelling methods, MMEI is the only covering all interoperability aspects [16], because it is based on the others presented maturity models. Besides these maturity models, we find other methods covering different aspects of interoperability such as the GRAI Grid that focuses on the decisional aspects of the management of CESs, i.e. it deals with organisational interoperability. The ETSI method covers conceptual and technical interoperability as it is designed to check the CESs standards interoperability and conformity. The i-Score addresses the evaluation of organizational processes interoperability. The EIDM compatibility matrix covers all interoperability aspects. However, it does not give a deeper insight on them. The Yahia et al. [21] approach assesses the conceptual interoperability between two CESs. It focuses on the semantic part of it. Finally, the ICT standards validation methods [23], [24] cover the technical interoperability and the syntactic issues from the conceptual interoperability. Table 1 summarises the coverage of the reviewed methods with regard to interoperability aspects.

Table 1. The coverage of the reviewed methods with regards to interoperability aspects. The '++' means "addresses the aspect", "+" stands for "relevant to the aspect" and '-' is for "do not addresses the aspect". Inspired from [16].

Name	**Conceptual**		**Technical**		**Organisational**	
	Semantic	**Syntatic**	**Standard**	**Platform**	**Organisation**	**Legal**
LISI	-	-	++	++	-	-
OIMM	+	-	-	-	++	-
LCIM	++	+	-	-	-	-
EIMM	++	+	-	-	++	+
MMEI	++	++	++	++	++	+
GRAI Grid	-	-	-	-	++	-
ETSI method	-	+	++	++	-	-
I-Score	-	-	-	-	++	-
EIDM – C. Matrix	+	+	+	+	+	-
Yahia et al. approach	++	-	-	-	-	-
ICT Standards validation	-	++	++	++	-	-

2.4. Analysis considering the method structure, measures and appraoch

Considering the structure-property, all the reviewed maturity models are levelling methods. The other approaches are non-levelling ones. Taking into account the used measure-property, the maturity models are considered qualitative methods. In general, they mainly define a five maturity levels' scale, where the lower level represents an ad-hoc and chaotic interoperation and the higher level represents a fully and effective interoperation. The intermediary levels represent the progression levels which CESs must pass through to achieve the higher level. Moreover, the GRAI Grid, ESTI method and the ICT standards validation methods [23], [24] are also considered qualitative methods. GRAI grid provides, as a result, a graph with all decision centres and information flow within the analysed CESs [17]. The ICT standards validation methods [23], [24] provide binary results, i.e. the standard is valid or not. The ETSI method [18] uses verdicts to classify if the CESs' test results are inconclusive, failed or successful. Furthermore, the identified quantitative methods are: the i-Score, EIDM compatibility matrix and the semantic interoperability approach of Yahia et al. [21]. Indeed, the assessment output of the i-Score is a real number ranging from 0 to 1, where 1 represents the CESs full interoperability. The EIDM approach provides a matrix with 24 interoperability areas where the value "1" is attributed when an incompatibility is found. The degree of compatibility is given by the sum of incompatibilities found, where "0" means higher compatibility and "24" poorest compatibility between the considered CESs. The Yahia et al. approach [21] provides two measures, calculating the potential and effective interoperability. It can also provide a qualitative result, i.e. it organises the numeric values into three categories: "0%" means "systems are not interoperable"; "0 <x< 100%" means "systems are partially interoperable" and 100% stands for "systems are fully interoperable". According to the used approach property, the only methods using the white box perspective are MMEI, the GRAI grid, the Yahia et al. approach [21] and ICT standards validation methods [23], [24]. These methods verify in-depth the different relations within the CESs elements, unlike the others (i.e. LISI, LCIM, OIMM, EIDM Compatibility Matrix and i-Score) that only use the black box approach. Table 2 summarises the analysis of the method properties and presents the value scales and metrics used by each assessment method.

2.5. Analysis considering the interoperability measurement

According to the type of interoperability measurement, we identify the following methods measuring interoperability after enterprises knowing their partner(s) : LISI, OIMM, LCIM, EIMM, ETSI method, i-Score, EIDM compatibility matrix, Yahia et al. [21] approach and finally the ICT standards validation methods [23], [24]. All these methods are capable to assess interoperability when two or more CESs within a NE are known. Moreover, we identify the following methods measuring interoperability before enterprises knowing their partner(s): MMEI and GRAI Grid. Both approaches are designed to assess the enterprises and its CESs capabilities without knowing their future partners. While not their focus, LISI and EIMM can also measure interoperability before interoperation partners are known. Indeed, LISI provides a matrix to calculate the potential technical interoperability of a given ICT system; EIMM states that an enterprise to achieve the maturity level 4 requires dynamic interoperability and adaptation without considering a specific partner. Table 2 also summarises the analysis of the mentioned types of measurements.

Table 2. Analysis of interoperability assessment methods. Where "S" means Structure, "M" means Measure and "A" means Approach. "L" stands for Levelling and "NL" for Non-Levelling. "WB" stands for White Box and "BB" for Black Box. "Qn" stands for Quantitative Method and "Ql" for Qualitative Method. "(1)" stands for "before knowing interoperation partner(s)" and "(2)" stands for "after knowing interoperation partners". The '++' means "addresses the aspect", "+" stands for "relevant to the aspect" and '-' is for "do not addresses the aspect". Inspired on [16].

Name	S	M	Value / Metrics	A	(1)	(2)
LISI	L	Ql	Maturity Level 0 to 4	BB	+	++
OIMM	L	Ql	Maturity Level 0 to 4	BB	-	++
LCIM	L	Ql	Maturity Level 0 to 4	BB	-	++
EIMM	L	Ql	Maturity Level 1 to 5	BB	+	++
MMEI	L	Ql	Maturity Level 0 to 4	WB	++	-
GRAI Grid	NL	Ql	Grid with Decision Centres	WB	++	-
ETSI method	NL	Ql	Interop. and Conformance Verdicts	BB	-	++
I-Score	NL	Qn	a real number ranging from 0 to 1	BB	-	++
EIDM – C. Matrix	NL	Qn	(0,1) for each interoperability area; 0-24 for final result	BB	-	++
Yahia et al.	NL	Qn / Ql	Qn: 0-100% representing the potential and effective interoperability; Ql: Not interoperable, Partially Interoperable, Fully Interoperable	WB	-	++
ICT Standards Validation	NL	Ql	(0-Not valid; 1-Valid)	WB	-	++

The analysis of these methods, allows us to identify their similarities and differences and which assessment type they prioritize. These findings will serve as a basis for the development of an assessment approach for CESs interoperability in the NE context.

2.6. Discussion

In order to achieve objectives targeted by a NE and its members, the CESs interoperability management, including the identification of problems, is a necessity. A simpler manner to avoid interoperability problems and consequently corrective actions, is to predict and solve potential problems before they occur [16]. For that, NE and its members need to plan and be prepared for future interoperations. To this end, enterprises can benefit from the application of an interoperability assessment method. However, as we can observe based on the analysis, MMEI is the only method that sufficiently covers all conceptual, technical and organisational interoperability aspects. Although, it performs only the interoperability measurement before partner are known. We have also found that the majority of the reviewed methods are measuring interoperability after interoperation partners are known, but they deal with a particular aspect of interoperability. Hence, we can assert that there is no method dealing with all interoperability aspects and addressing both types of measurements. Based on that, we propose to elaborate an assessment approach for CESs interoperability. This approach will be developed to be applied in the Networked Enterprise context, regardless the enterprise members' size, discipline, location, etc. It will deal with types of measurements. It will also cover the main aspects of existing maturity models and non-levelling methods, combining *qualitative and quantitative* metrics to consider both subjective and objective values. We intend to use a *white box* view to consider the different interactions and variables of the CESs to be assessed.

3. Conclusion and Future work

In this paper, we have proposed a comparative analysis of the main relevant evaluation methods regarding the CESs interoperability. Prior to that, an investigation about the relations between interoperability and Networked Enterprise contexts has been done. This allowed the identification of what need to be verified during an interoperability assessment, when considering the different interoperability aspects and its related barriers. Moreover, the identification of the method properties including the different types of measurements has been used to analyse current evaluation methods dealing with multiple interoperability levels. Based on this analysis, we observed that there is no evaluation method addressing sufficiently both considered types of measures as well as not covering all interoperability aspects. As future work, we intend to propose an interoperability assessment approach for CESs covering all interoperability aspects as well as both considered types of measurements. This will be tackled by the extension of MMEI to both considered types of measurement contexts. Quantitative methods will also be used to provide objective results. Furthermore, combining this CES interoperability assessment approach with NEMO, will allow us to build a Framework for Networked Enterprise Interoperability. The NEMO approach has been chosen because deals with all interoperability aspects (c.f. section 1.1) and it covers the two contexts (1) the unknown partners and (2) the known ones. This framework will serve as basis to the development of a decision-support system for preventing and solving Collaborative Enterprise Systems Interoperability problems in a collaborative and transdisciplinary context.

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Part 3

Design Tools and Methods Within CE

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Transdisciplinary Engineering: Crossing Boundaries
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Classification and Use of Methods and Tools in New Product Development

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Abstract. The new product development (NPD) is considered an important business process to determine the competitive advantage of companies. In order to launch products successfully, methods and tools have been applied by companies for improving and supporting the activities performed in that process. However, a comprehensive and integrative classification of new product development methods and tools is not clear. Beyond that, regarding how useful the practitioners consider the methods and tools, the adoption, diffusion and application dimensions of them are still research challenges. To address these issues, the aim of this research is to present a classification of methods and tools, besides to present which of them are really applied and useful in new product development of companies. The novelty of this proposal involves the practical perspective encompassing the practitioner's point of view, which goes beyond the theoretical perspective. Methods and tools identified by means of literature review were classified using a qualitative approach. The classification was validated by practitioners of ten companies specialized in product development. Key findings of the classification proposed are presented based on the following categories: performance objective related, added value, complexity and implementation cost. Finally, the research provides an overview of the usefulness and attractiveness of methods and tools. It can support a valuable guidance for companies in order to improve the use of the most useful ones.

Keywords. New product development, methods, tools, classification, application

Introduction

The new product development (NPD) has been recognized as one of the most critical processes of companies in today's competitive business environment [1],[2],[3]. Therefore, manufacturing companies are challenged to improve their NPD [4],[5],[6], once they are operating in markets that demands innovation, shorter time-to-market, product diversity and higher quality product. In order to achieve a better performance, Rossi et al. [7] claim that companies can apply a set of practices, which encompass methods and tools that lead to the development and launch of new products [3],[8],[9]. Methods and tools can support the NPD activities and the appropriate adoption of them are essential for achieving satisfactory results [6],[9],[10].

Although some authors have studied the positive impact of NPD methods and tools [4], there are still some research challenges on the NPD literature [11]. The application of them, regarding the adoption and diffusion among a group of organizations, is not

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systematized [4],[6],[11],[12],[13] – i.e. the literature is sparse in examining the implementation of methods and tools in manufacturing companies that develop products. Furthermore, there are some studies that do not consider the usefulness of methods and tools under the context of NPD [11]. Concerning the practical application, the companies should understand if they are applying the appropriate methods and tools based on real situation of their NPD [6]. Additionally, some factors may influence its adoption or non-adoption [12]. A comprehensive and integrative classification which encompasses a benefit-cost analysis is not widely present in NPD literature works. Previous researches [11],[13],[14] only propose perspectives for organizing framework for methods and tools. However, it is essential a classification that helps the practitioners and academics to analyze the trade-off that some companies have to face when applying the methods and tools on their NPD [12].

In order to contribute with the aforementioned gaps, the aims of this research are to analyze the use and usefulness of the methods and tools in NPD of companies, and to present a classification based on the cost-benefit analysis to address the strengths and weaknesses of each one.

This paper is structured as follows. After the enlightenment of the research background (section 1), it is described the research methodology (section 2). Following, the results and discussions are presented (section 3), comprising: the analysis of use and usefulness of NPD methods and tools, and the cost-benefit classification of them. Lastly, a section of final remarks is presented (section 4).

1. Background

The success of NPD is related to the application of best practices [5],[15], which are the activities, methods, techniques and tools that generate the best results for the process [3],[7],[16]. They provide the reach of greater process performance, with positive reflexes in the product. Specially the effective use of methods and tools on NPD can generate satisfactory outcomes for that process [13].

Method is defined as a systemic procedure employed to perform an activity in order to achieve a desired result, whether an information, product or service [17]. Graner and Mißler-Behr [4] affirm that a method can involve the use of tools, which support practitioners when an activity is carried out. In NPD, the methods and tools can enable practitioners to monitor and evaluate the process and product projects systematically [6]. Because of this, in order to improve the NPD, methods and tools have been developed by researchers and practitioners [12],[14],[18].

The adoption of methods and tools can be at the level of company or at the level of individual development projects [13]. Independently of the level of adoption, some internal and external factors may affect the use of methods and tools in the NPD of companies [12]. On the one hand, the internal factors include the usefulness, time, monetary cost, user-friendliness, flexibility and popularity [12]. Additionally, the complexity of methods and tools may influence their use [13]. On the other hand, external influences encompass the project nature, organization, industries and culture [12]. These factors can involve potential benefits or drawbacks for companies and represent critical decision aspects when practitioners are selecting which methods or tools will be implement in the NPD.

According to Maylor [19], the NPD methods and tools can improve flexibility and can affect the manufacturability, time to market, quality and product cost. Also, this author suggests that the use of them can be associated with the integration of engineers, designers, customers and suppliers.

Yeh et al. [6] presented other elements to be considered in NPD system when methods and tools are applied. They are: customer perception, value addition, tangible and intangible outcomes. Furthermore, it has been shown that different methods and tools can be used in various stages of NPD. It should be noted that methods and tools could overlap a NPD stage. In fact, they can be adapted to meet different needs or characteristics of NPD by companies [11].

Some studies [1],[13] reveal that successful projects use methods and tools more frequently than others, even in the early stages of the process. The benchmarking study conducted by the Product Development & Management Association (PDMA) found that best firms use numerous kinds of methods and tools compared to “the rest” [9]. However, the impact on success varies from method-to-method [13] and, consequently, from tool-to-tool.

Regarding the nature of the methods and tools, it is possible compile them in perspectives, which can support an efficient NPD. Some of them are: strategy [3], process [3], market research [3], performance measurement [3], project management [17], knowledge management [20], product [20], organizational culture and climate [3], and information technology [11]. These perspectives allow practitioners selecting and develop appropriate activities using methods and tools in order to increase the process performance. It provides knowledge and experience for companies [13], besides contributes for an effective innovation management of process and product [1].

Thereby, as the NPD is fundamentally multidisciplinary and multifunctional [11], it is important to address the multi-faceted aspects correlated with it for driving the right methods and tools that lead to successful process and products.

2. Research Methodology

In order to reach the aims of this research, firstly the NPD methods and tools discussed in the literature have been consolidated. For it, an exploratory methodological approach was employed and a literature review was carried out. An electronic data-base search was applied to enable a comprehensive search, in which were used the ISI/Web of Science and Scopus databases. Iterative searches were conducted by combining synonyms, acronyms and abbreviation related to the terms “new product development”, “practice”, “method”, “technique”, “tool”. Boolean search expressions were elaborated, and only studies in English were considered. Two criteria of inclusion were used to select the studies, as follows: investigate the use of methods and tools in the context of NPD and/or show their positive effectiveness. The screening included the title and abstract screening as well as a full copy screening. From these studies, the NPD methods and tools were extracted and coded.

The quantity of methods and tools consolidated from literature review is substantial (one hundred and twenty). Due to that, a selection process of them was conducted. As mentioned previously, the improvement of NPD can be established by the application of practices, as methods and tools. Considering this issue, the resultant findings were associated to improvement projects found in literature consolidated in Costa [20] and Zanatta [21]. The association between the methods and tools with the improvement projects was performed using a qualitative approach based on the content-based analysis, on which the steps adopted were in accordance with the proposal of Bardin [22]. The scope and objectives of the improvement projects were analyzed and interpreted. Then, the methods and tools were related to them. By doing that, a total of fifty more recurrent methods and tools - i.e. that have the highest frequency in the set of improvement projects for NPD - were selected and categorized into NPD perspectives.

To further comprehend the use and usefulness of methods and tools by companies, and in order to examine in what extent their application are costly and beneficial, a workshop was carried out with twenty-four experts on product development – executive managers, project managers, design engineers, among others – by ten manufacturing companies, whose profiles are shown in Table 1.

Table 1. Manufacturing company profiles.

Ref.	Industry Sector	Size
A	Automobile	Medium
B	Automobile	Large
C	Capital goods	Large
D	Dental and hospital	Small
E	Automobile	Large
F	Aviation	Large
G	Chemical	Large
H	White goods	Medium
I	Consumer goods	Large
J	Automobile	Large

The focus group technique [23] was employed. The involvement of the participants was enabled through the application of the card sorting method, which is prescribed when researchers would like to understand how people organize and apply a set of information [24]. As the method name suggests, cards were proposed containing the definition and a predefined classification concerning the fifty selected methods and tools. The preparation stage of cards was performed based on information from literature review. Then, the categories supporting the classification were defined by means of analyses of the main factors that influence the adoption and non-adoption of methods and tools (for it, it was considered the studies of which the methods and tools were extracted). Those factors were defined considering the following criteria: expected impact on NPD, likely contribution for NPD, challenge for application, and effort to implement. The categories are presented in the next sections.

In addition to the preparation stage of cards, the sorting process was also specified. That process allows the grouping of information and the understanding of how practitioners can associate the methods and tools in the categories. Five groups were generated composed by experts of two companies, each one. After the warm-up discussion in order to contextualize the dynamic of the focus group session, the research background and the main goals of the sessions, three stages of focus group were performed: i) recognition of methods and tools by practitioners; ii) real application of the methods and tools in NPD by companies, considering the use and usefulness of each one; iii) classification of methods and tools in accordance with the four categories defined.

The findings of each stage of focus group were consolidated and it is the focus of the following section.

3. Results and Discussion

3.1. Recognition of NPD methods and tools

The most recurrent and relevant NPD methods and tools are consolidated in Table 2. Those methods and tools can be classified in different perspectives of NPD based on the scope of each one. The main perspectives related to the methods and tools listed in Table 2 are strategy, process, market research, performance measurement, project management, product, organizational culture and climate, and information technology. Thus, they can be carried out by different users of NPD, either more or less intensely.

Overall, the practitioners who participated in the workshop knew the methods and tools presented through the cards. They argued that the methods and tools are relatively traditional in the practical application in NPD. A lesser-known method by the ten companies is 'set-based concurrent engineering'. This method encompasses the development and communication "about set of solutions in parallel and relatively independent" [28], not only in the front end of innovation (FEI). As this method is not widely known, it is expected that only few companies use it.

Table 2. Fifty most revelant NPD methods and tools.

Method/Tool	Perspective	Author(s)
Technology and product roadmap	Strategy	[11]
Product portfolio management	Strategy	[11],[25],[26],[27]
Technology trend analysis	Strategy	[11]
Set-based concurrent engineering	Strategy	[28]
Stage-gate	Process	[7],[9],[11],[14],[29]
Flexible process	Process	[5], [27],[29]
Enterprise Resource Planning	Information technology	[11]
Market research	Market research	[5]
Customer observation	Market research	[13]
User-centered design	Market research	[11]
Benchmarking	Market research	[6],[11],[13]
Customer support	Market research	[5]
Customer integration	Culture and climate	[5],[7],[13],[27]
Supplier integration	Culture and climate	[6],[13],[14]
Collaborative Design	Culture and climate	[6]
Cross-functional teams	Culture and climate	[5],[6],[7],[11],[14],[26]
Incentives and rewards	Culture and climate	[5],[9],[25]
Project management	Project management	[6],[11]
Project Management Office	Project management	[17]
Critical path analysis	Project management	[11],[13]
Work breakdown structure	Project management	[17]
Project review meeting	Project management	[5],[11]
Metrics use	Performance measurement	[7],[27]
Knowledge management	Knowledge management	[6],[11]
Training	Knowledge management	[7]
Value engineering	Product	[6],[11],[18]
Financial models	Performance measurement	[11],[13]
Make-or-buy analysis	Product	[13]
Modular design	Product	[6],[13],[14]
Group technology	Product	[6],[13],[14]
Design Failure Mode and Effect Analysis	Product	[6],[11],[13],[14]
Product Failure Mode and Effect Analysis	Product	[6],[11],[13],[14]
Fault tree analysis	Product	[11],[18]
Quality Function Deployment	Product	[6],[11],[13],[14],[18]
Brainstorming	Culture and climate	[6],[11],[13]
Design of Experiments	Product	[6],[11],[18]
Statistical process control	Process	[11],[14]

Method/Tool	Perspective	Author(s)
Product Life-Cycle Management	Information technology	[11]
Product Data Management	Information technology	[6],[14]
Engineering Change Management	Information technology	[11]
Electronic Data Management	Information technology	[11]
Computer-Aided Design	Information technology	[6],[11],[13],[14]
Computer-Aided Engineering	Information technology	[6],[11],[13],[14]
Computer-Aided Manufacturing	Information technology	[6],[11],[14]
Workflow	Information technology	[11]
Design for assembly	Process	[6],[13]
Design for manufacturing	Process	[6],[13]
Design for cost	Process	[11]
Design for reliability	Product	[11]
Design for six sigma	Product/Process	[6],[11],[13]

The results related to the use and usefulness of methods and tools are presented in the following subsection.

3.2. Use and usefulness of NPD methods and tools

Practitioners were encouraged to analyze the applicability and usefulness of each method and tool in accordance with the reality in the NPD of companies. Thus, four classes related to the use or non-use of each one, and the degree of usefulness (very or little useful) were defined. Table 3 presents the percentage of companies that associated the respective method or tool in each class.

Six methods/tools are used and considered very useful by all the companies: stage-gate, cross-functional teams, benchmarking, enterprise resource planning, project management and computer-aided design. This indicates that all the companies use a formal process model of product development, in which the participating team encompasses practitioners from different functions and they act from start to finish of the project. Other practice performed by the companies is the comparision of their process performance in relation to industry leading companies. It helps companies to develop improvement plans. Also, they use an information system to collect and group the data and information regarding the process and product. The use and usefulness of computer-aided design in all the companies show that this information technology can be applied for all type of manufactured products.

Although the project management methods have the highest frequency of use, only five companies have a project management office; not all companies consider it very useful. The practitioners claimed that the methods/tools examined as little useful are not applied under the context of their NPD. This demonstrates that a method and tool are context dependent and they can be more suitable to be used in certain circumstance. At the same time, there are methods and tools used by companies, but assessed as little useful, e.g. brainstorming. In that cases, resources are being spent even not reaching a satisfactory and desired result with the application of the method or tool. Thus, the analysis of the existing and desired situations for NPD is important when selecting which method or tool should be applied.

There are some methods/tools do not widely used by companies, but they are considered very useful. They are: flexible process, collaborative design and knowledge management. Among other methods, set-based concurrent engineering is used only by three companies, but four of them would like to apply it on NPD. Some reasons explained by companies by do not use the methods/tools considered very useful are: financial or cultural aspects and an extended time for implementation.

Table 3. Use and usefulness of methods and tools by companies.

Method/Tool	Uses		Do not use	
	Very Useful	**Little useful**	**Very useful**	**Little useful**
Technology and product roadmap	80 %	20 %	0 %	0 %
Product portfolio management	80 %	0 %	10 %	10 %
Technology trend analysis	90 %	0 %	10 %	0 %
Set-based concurrent engineering	30 %	10%	40 %	20 %
Stage-gate	100 %	0 %	0 %	0 %
Flexible process	50 %	0 %	50 %	0 %
Market research	80 %	0 %	20 %	0 %
Customer observation	50 %	0 %	30 %	20 %
User-centered design	60 %	0 %	10 %	30 %
Benchmarking	100 %	0 %	0 %	0 %
Enterprise Resource Planning	100 %	0 %	0 %	0 %
Customer support	70 %	10 %	10 %	10 %
Customer integration	60 %	0 %	20 %	20 %
Supplier integration	90 %	0 %	0 %	10 %
Collaborative Design	40 %	10 %	50 %	0 %
Cross-functional teams	100 %	0 %	0 %	0 %
Incentives and rewards	50 %	10 %	40 %	0 %
Project management	100 %	0 %	0 %	0 %
Project Management Office	50 %	10 %	30 %	10 %
Critical path analysis	80 %	0 %	30 %	0 %
Work breakdown structure	80 %	0 %	20 %	10 %
Project review meeting	90 %	0 %	10 %	0 %
Metrics use	80 %	10 %	10 %	10 %
Knowledge management	30 %	10 %	60 %	0 %
Training	90 %	0 %	10 %	0 %
Value engineering	50 %	0 %	30 %	20 %
Financial models	80 %	0 %	10 %	10 %
Make-or-buy analysis	80 %	0 %	20 %	0 %
Modular design	70 %	0 %	20 %	10 %
Group technology	90 %	0 %	0 %	10 %
Design Failure Mode and Effect Analysis	90 %	0 %	10 %	0 %
Product Failure Mode and Effect Analysis	80 %	0 %	20 %	0 %
Fault tree analysis	60 %	0 %	40 %	0 %
Quality Function Deployment	70 %	10 %	10 %	10 %
Brainstorming	80 %	20 %	0 %	0 %
Design of Experiments	70 %	10 %	10 %	10 %
Statistical process control	90 %	10 %	0 %	0 %
Product Life-Cycle Management	60 %	0 %	40 %	0 %
Product Data Management	80 %	0 %	20 %	0 %
Engineering Change Management	90 %	0 %	10 %	0 %
Electronic Data Management	90 %	10 %	0 %	0 %
Computer-Aided Design	100 %	0 %	0 %	0 %
Computer-Aided Engineering	80 %	0 %	0 %	20 %
Computer-Aided Manufacturing	80 %	0 %	0 %	20 %
Workflow	80 %	0 %	20 %	0 %
Design for assembly	60 %	0 %	30 %	10 %
Design for manufacturing	90 %	0 %	10 %	0 %
Design for cost	70 %	0 %	30 %	0 %
Design for reliability	90 %	0 %	10 %	0 %
Design for six sigma	50 %	0 %	30 %	20 %

In this context, some factors may influence the adoption of the methods and tools. Therefor, they also influence in their cost-benefit analysis. The factors are presented in the next section, which also presents a classification for the NPD methods and tools.

3.3. Cost-benefit classification of NPD methods and tools

The cost-benefit analysis of NPD methods and tools is proposed by means of a classification which encompasses four criteria. For each one, a category was defined. Table 4 summarizes it.

Table 4. Criteria and categories for classification of methods and tools.

Criteria	Category	Definition	Author(s)
Expected impact	Performance objective	- It includes the performance factors that are reached when a method or tool is applied.	[19]
Likely contribution	Added value	- It concerns the contribution and differentiation of methods or tools for NPD.	[6]
Challenge for application	Complexity	- It refers to the challenge and the team knowledge needed for implementing a method or tool in NPD. Also, it is related to the amount and types of resources involved and the degree of change or adaptation required for the process.	[13]
Effort to implement	Implementation cost	- It is related to the efforts employed to implement a method or tool. It considers e.g. the acquisition of resources and technology, training, staff time spent, etc.	[12]

The classifications, by practitioners, of the methods and tools for each category were consolidated and it is presented in Table 5. Classifications by companies that do not apply the method/tool were not considered. The defined performance objectives are: quality (Q) (even of the process or product, according to the scope of methods/tool), time (T) and cost (C) of development. The range of the other three categories varies and can be: high (↑), medium (→) or low (↓).

All available methods/tools have a high or, at least, medium value added - i.e. they positively contribute for NPD. Almost 62% of methods/tools affect the objectives of quality, time and cost, simultaneously. The methods/tools used for all companies (that were presented in section 3.2) impact on the three performance objectives. The methods/tools do not used by companies, but which were considered very useful, also impact the three performance objectives. This fact indicates the need for improving the NPD of companies. In the cases in which a method/tool is related to a high complexity do not mean that the implementation cost will be high, and vice versa. For example, the design failure mode and effect analysis is associated with a high complexity, but also with a low implementation cost. So, the companies should analyze whether they have the knowledge or efforts required to implement the NPD method or tool.

Thus, this indicates that when performing the cost-benefit analysis, all factors that influence the adoption of a method or tool should be evaluated.

Table 5. Classification of methods and tools.

Method/Tool	Objective	Added value	Complexity	Implementation cost
Technology and product roadmap	Q; T; C	↑	↑	→
Product portfolio management	Q; T; C	↑	→	→
Technology trend analysis	Q; T; C	↑	↑	→
Set-based concurrent engineering	Q; T; C	↑	↑	↑
Stage-gate	Q; T; C	↑	↑	→
Flexible process	Q; T; C	↑	↑	→
Market research	Q; T; C	↑	→	↑
Customer observation	Q; C	→	↑	↑
User-centered design	Q	↑	→	↑
Benchmarking	Q; T; C	→	→	↓
Enterprise Resource Planning	Q; T; C	↑	↑	↑
Customer support	Q; T; C	↑	→	→

Method/Tool	Objective	Added value	Complexity	Implementation cost
Customer integration	Q; C	↑	→	→
Supplier integration	Q; T; C	↑	↑	→
Collaborative Design	Q; T; C	↑	↑	→
Cross-functional teams	Q; T; C	↑	→	→
Incentives and rewards	Q	→	→	↓
Project management	Q; T; C	↑	→	→
Project Management Office	Q; T	↑	→	↓
Critical path analysis	T; C	↑	→	↓
Work breakdown structure	Q; T	↑	→	↓
Project review meeting	Q; T; C	↑	↓	↓
Metrics use	Q; T; C	→	→	↓
Knowledge management	Q; T; C	↑	→	→
Training	Q; T; C	→	→	→
Value engineering	C	↑	→	→
Financial models	C	↑	→	→
Make-or-buy analysis	Q; T; C	↑	→	↓
Modular design	Q; T; C	↑	↑	→
Group technology	Q; T; C	↑	→	→
Design Failure Mode and Effect Analysis	Q; C	↑	↑	↓
Product Failure Mode and Effect Analysis	Q; C	↑	→	↓
Fault tree analysis	Q	→	→	↓
Quality Function Deployment	Q; C	↑	↑	→
Brainstorming	Q; T; C	→	↓	↓
Design of Experiments	Q; T; C	↑	→	→
Statistical process control	Q; C	→	↓	→
Product Life-Cycle Management	Q; T; C	↑	↑	↑
Product Data Management	Q; T	↑	↑	↑
Engineering Change Management	Q; T; C	↑	↑	↑
Electronic Data Management	Q; T	↑	→	→
Computer-Aided Design	Q; T; C	↑	↑	↑
Computer-Aided Engineering	Q; T; C	↑	↑	↑
Computer-Aided Manufacturing	Q; T	↑	↑	↑
Workflow	T	→	→	↓
Design for assembly	Q; T; C	↑	→	→
Design for manufacturing	Q; T; C	↑	→	→
Design for cost	C	→	→	→
Design for reliability	Q	↑	↑	→
Design for six sigma	Q; T; C	↑	↑	→

4. Final Remarks

This study provides a systematic evaluation of some NPD methods and tools. Its main academic and managerial contributions are: i) the systematization of the main NPD methods and tools; ii) the overview of the use, usefulness and attractiveness of them; iii) the introduction, based on a classification, of a valuable cost-benefit analysis that can help companies to improve their NPD. Adopting the involvement of practitioners is also a contribution of this research, once the findings achieved are based on practical perspective encompassing their' point of view. The findings clearly confirm the importance to improve the NPD of companies based on their context, once some methods and tools are considered very useful, but are still not applied. Also, the findings indicate that companies should be prepared to implement the NPD methods and tools, once they are related to different complexity and implementation cost. Next steps of research aim to analyze the selection of methods and tools in accordance with the NPD strategy and case studies will be performed to evaluate their applicability.

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Discussion on Generic Innovation Models and New Product Opportunity Identification

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Abstract. Ideas and opportunities are often seen as the same, but there are differences and shared similarities that imply on the way one can achieve and research about them. Creative solutions by creative people are always welcome and can be somewhat improved by technical training or crowdsourcing. However, the recurrent ability to address or to be driven by the value spark that makes the idea a winner still demands research and tools. A new valuable product idea is a complex entity. This paper presents a brief investigation of theoretical innovation models with a focus on its mechanisms for identifying new product opportunities. The work aims to complement partially the research conducted by Kampa [1], which features an emphasis on approaches presented by classical New Product Development Process (NPD) models. An exploratory study was conducted on generic innovation models and its main stages in order to identify how new product opportunities are treated in them. It was seen thatfew procedural detailsare offered, and that the topic has been mainly discussed on idea management models. Despite their aim on the idea part of the equation, it is clearly noted that the opportunity identification mechanisms should be investigated within these areas, somewhat segregated as sources on NPD researches, and should involve works on idea management models and open innovation models.

Keywords. Innovation Models; New Product Development Process; Opportunity Identification.

Introduction

According to Baron and Shane [1], recognize a market opportunity is the first step of entrepreneurial activities. The development and launch of a new product represents one of these actions, in which it is possible to obtain different advantages when it is agile and incorporates innovation.

Annacchino says that companies need to become proficient in recognizing opportunities [2]. However, studies reveal that it is a casual and so little systematized in most companies [3][4][5][6]. Also in the academic field, the subject is deeply related to entrepreneurship and business development but little is explained on the product development side. The new product ideas or new product opportunities are often expressed as a starting point in the New Product Development Process (NPDP) models. But it is noted that the terms are used in a confusing way. New product ideas are often expressed as a new valuable solution to a new or to an existent problem. Wille a valuable new product opportunity, based on the entrepreneurship literature, can be seen

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as a latent problem that a group of individuals has and is willing to pay a certain amount of money for a solution that can be embed in a product. Ideas are complex because they must address two valuable entities, the problem and the solution in a way that estimulates a value exchange. The problem may persist or evolve without the existance of a solution, as a central need, and can be used on idea generation efforts, even on cycles, while the technology becomes feasible and cheaper to be offered as a new product or an improved one. The central need can define an industry, a whole new business, and its changes can be as critical as on the technology [7].

There are several methods to support people on the creative side. But little is known on methods to identiffy potentially valuable problems, even the ones who reside on the new product ideas. Kampa [7] investigated different proposals for this purpose, especially Kim and Maubourgne [5] called Blue Ocean Strategy (BOS), that essentially works by redefining the central problem and, consequently, the value offer and/or the offer capability (product and/or business). However, the original investigation did not involve the study of innovation models. In particular, the proposal did not explore the open innovation model, derived from pioneering studies such as Chesbrough [8], which developed and consolidated in recent years [9]. Thereby, there is a research opportunity in this work to investigate and discuss different innovation models and its proposals for opportunities identification. As a result of this study, new perspectives are sought to the Kampa [7] proposal enhancement, as a doctoral research in progress, aimed at contributing to the systematization of innovation in enterprises and among entrepreneurs.

1. Methodology

This study is characterized as exploratory research on previously developed materials and available in books and scientific articles. The study consists of searching these texts, sorting, reading, analyzing and drawing conclusions. As the product of this research is to provide a brief overview on the innovation models and opportunities identification, the research questions that shall be are explicitly stated: How different innovation models and innovation management systems deal with opportunities identification? Do they treat opportunities on a different way than ideas?

The books consulted were the ones available in UTFPR, campus Curitiba, central library. There were searches for the topics "innovation models" and "opportunity identification", as well as their main interface with the theme "open innovation" in Capes periodic portal data bases (www.periodicos.capes.br). The main selection criterion was their relationship to the theme and the objective of raising a general theoretical framework. Thus, after the initial screening, the sample was reviewed and there were the compilation of texts that comment on its peculiarities. At the end, it is proposed some new research perspectives. Next is an overview of the models and similar work.

2. Opportunity identification and the NPDP

On the following some peculiarities about the perception of opportunities are treated, as well as the processes that tend to incorporate it, as the NPDP. In this work it is assumed that the theory about entrepreneurial opportunity identification is valid on the search for new products, services or business models.

2.1. Identifying opportunities as a human factor and the product life cycle

Identifying a new product development opportunity involves the perception of a latent problem that a group of individuals has and is willing to pay for a solution in the form of a product ([7], based on Stull, Myers and Scott [10]) . The new product idea, in turn, can be seen as a solution embryo [11], as one of the multiple ways in which one intend to exploit an opportunity.

Baron argues that not every idea can be an opportunity, because the existing technology on a given time can make it impossible to generate economic value from it [12]. As the technology evolves, the technical and finantial feasibility could be reached and the idea or opportunity becomes more apparent to everyone concerned about it. The more fully developed opportunities for value sought or value creation are, the more likely they are to become perceptible to a wider array of individuals [13]. But, as one can employ the original problem as a guide to the technology development, or trying to find a distinguishing problem to a new technology application, the question about the creation or recognition of opportunities becomes intriguing.

There is a fine line between idea and opportunity and if they are recognized or constructed, depending on the line of reasoning that one decide upon thinking about it. On the new business side, Vaghely and Julien review and discuss two diferent perspectives based on economics and entrepreneurship theories to face the problem: the cognitivist or constructionist perspectives [14]. From an epistemological point of view, cognitivists use formal models or algorithms to recognize opportunities and the constructionist perspective uses interpretative or heuristic models to construct opportunities. This algorithmic–heuristic duality forms an information processing continuum entrepreneurs can rely on recognizing or constructing opportunities [14], as one individual can use both perspectives. As can be seen, the topic embraces several theoretical gaps.

Assuming a cognitvist perspective, Venkataraman apud Yenchen and Gillin comments that people generally recognize the opportunities related to the information they already have [15]. Baron comments that some people are more proficient in recognizing opportunities than others, and he establishes a series propositions that have direct influence on the recognition opportunities [12]:

1. Proposition 1: opportunities emerge from a complex pattern of changing conditions;
2. Proposition 2: the change of these conditions create the potential opportunities, but there are no guarantees that opportunities are indeed recognized or exploited even if they are recognized;
3. Proposition 3: opportunities exist in the external world in the sense that there is actually a pattern of events (stimuli) that together provide the basis for them. Until the opportunities are recognized by an active human intellect, however, they remain merely as potential. Thus, opportunities are emerging in specific human minds that, in a sense, "connects the dots" between various changes and changes or events apparently uncorrelated to form the perception of a pattern that connects;

4. Proposition 4: recognition opportunities depends, in part, of existing cognitive structures held by specific individuals that are the result of prior experience or learning. These structures (ie schemes, prototypes, concepts, memories) serve as structures or models that allow that certain people perceive connections between changes, knowledge, or events, hitherto disconnected. It is the perception of these links or connections that forms the core of recognition opportunities;
5. Proposition 5: opportunities themselves are unique, but the basic processes that play role in their recognition are the same in all cases.

Thus it is essential to have individuals with the proper repertoire as it is possible give them tools or procedures (algorithms) that stimulate the basic processes of pattern recognition in a given time. This must be agile, as opportunity identification (being it recognized or constructed) is also time-sensitive/time-dependant [14]. On the new product opportunities side the time dependancy is clearer. There is a finite period, also called the window of opportunity (WO), which one can identify and exploit economically a new product opportunity. This window opens when the opportunity occurs and closes when the product is extinguished. The potential gain of a given WO is demarcated by the interval between the appearance and the perception an opportunity and the beginning of the project aimed to capitalize it. If it can be reduced, it can advance the launch and the period comprising the net income may increase [15].

It is believed that reducing this period can occur through continuous investments in prospecting new opportunities with the use of *adhoc* systematics that stimulate the individuals perception involved in prospecting [16].

2.2. New product development process models and the opportunities identification

In an overall level the new product development consists of three macro-phases: pre-development; development; and post-development [17].

However, in the pre-development, which address the new product opportunities or ideas, there is no clear chain of tasks and tools such as occurs in development activities in the classical models of Pahl *et al.* [18], Rozenfeld *et al.* [17], and Back *et al.* [19] practiced worldwide and in Brazil [7]. Those who approach the subject lack the operational details, such as Cooper [4] and Annacchino [2]. Except Cooper [4], Cooper and Edgett [6], Koen *et al.* [20] and [21] little is said about how to find out new product development opportunities. Even on the pre-development, the Strategic Planning Process (SPP) do not discuss in detail the identification of opportunities [7]. As can be inferenced by the Kaplan and Norton [22] propasal, one notes that it is not the specific function SPP to identify new products opportunities. However, it is part of SPP identifying growth opportunities or at least the definition of the areas of strategic interest, or growth, on these opportunities should be prospected [7].

Works like proposed by de Carvalho [23], focus on the ideation side of the process. A methodology to generate innovative and valuable new product ideas (solutions) is suggested. This and other similar initiatives focused on the ideation of new products (essentialy through crowndsourcing), represent a part of the state of the art on the subject. A massive number of new product ideas can be reached on this way, which lead to the problem of sorting the best ones. However, there are still a research gap on the question that seems to preceed the ideation effort and that is necessary to start any crowdsourcing campain: how one can identify a valuable problem, which can be solved through a new product idea? It is believed that if this question really preceed the ideation of new products, its solution can contribute to any ideation and idea selection methodology.

It was seen that the innovation models tend to explain and to discuss mechanisms for identifying innovation opportunities, although their relationship or engagement with the NPDP or the SPP still is not presented in an integrated manner.

3. Innovation management perspective

Next are some perspectives on identifying opportunities from the innovation management perspective.

3.1. Generic innovation models and the opportunity identification

Carvalho, Reis and Cavalcante [24], mentions four innovation models: Linear Model; Parallel model; Model Tidd, Bessant and Pavitt [25]; and Open Innovation Model.

According to them, the linear model has emerged from the Second World War. It follows a sequence involving basic research, applied research, experimental development, production and marketing. This model features instabilities according to the interests and influence of different independent actors. Companies that follow this model extensively tend to lose competitiveness because it can lead to not necessarily relevant products for its market [24]. It is noted that this model does not explicitly points the opportunity identification as an innovation development stage. It is seen as outdated front the contemporary dynamic between industry and market. However some fundamental similarity is noted to the situation when one decide to find new applications to a new technology.

The parallel model is an evolution of the linear model [24]. It states the knowledge advances can be leveraged by companies to produce goods and services (with or without technology) or to provide feedback to science with technological advances contributions. Therefore, the relationship between science, technology and innovation occurs in different directions. In this model is explicit the need to identify innovation opportunities. A new product or significantly improved service development process (innovation process) can be generated considering the demands of society translated into opportunities, with or without previous inventive process. These are generated in-house or purchased/negotiated with research institutions, universities or even other organizations. In it the company seeks and uses information about the needs of potential customers (society) and new technologies (scientific and technological knowledge). Their adoption grows when companies begin to formalize their product development models [24]. It is noted that the NPDP models studied shows a general logic similarity to this approach. It is interesting to note that the identification of opportunities on this model can occur without the first inventive step, as discussed in Kampa [7].

Carvalho, Reis and Cavalcante [24] comment that one of the models that have grounded the innovation processes is proposed by Tidd, Bessant and Pavitt [25]. In it, in a simplified manner, the phases are incorporated to search, select, implement and learn. At the stage of seeking new opportunities are raised considering changing needs imposed by the market, political pressures and competitors. This model is very general and needs to be adapted to be applied, but it is open and incorporates context influences dynamically. Its simplicity favors its conceptual adoption, but the lack of operational mechanisms affects praticality. However, it can represent a future research focus on the methods employed by its practioneers.

In the open innovation model these context influences are further explored. According to the authors mentioned above, it incorporates all interaction concepts of previous models and makes acting beyond its borders [24]. With it joint search practices are adopted for selection, implementation and learning both inside out and outside in company. This model is much more comprehensive than the traditional processes of new product development, as it explores assets not emphasized by these. Regarding the opportunities identification, it is noted that this model explores different fronts by the practice of internalization. It involves everything that is value for the company and that can be traded at some point in the innovation process. Initially by the search for ideas and technologies from different sources and that are of interest to start the process of research, development and commercialization. But internalization can run with patents, know-how, prototypes, and other elements that represent an opportunity to gain value. This model can be seen as one of the most promising and deserves further study of its mechanisms to promote the opportunities internalization. However, on the work of Cherbrough [8] examples of cases were found, but no explicit procedure for such. According Trentini et al. [26] in this context, another recent concept in the field of open innovation concerns the distributed innovation. Distributed innovation is held in around a common good, with the participation of many people, and often voluntary ways. For them, because it is a recent approach to the innovation process, open innovation models and distributed innovation models are presented interlaced in the literature.

Table 1 summarizes the innovation models presented by Carvalho, Reis and Cavalcante [24] on the opportunity identification.

Table 1. Comparative between the approaches on the innovation models.

Linear model	Parallel model	Tidd, Bessant and Pavitt [25] model	Open innovation model
Does not explicitly points the opportunity identification as an innovation development stage Opportunity identification can be inferred on the finding of new applications to a new or existent technology It is seen as outdated	Explicit the need to identify innovation opportunities A new product or significantly improved service development process can be generated considering the demands of society translated into opportunities, with or without a previous inventive process The company seeks and uses information about the needs of potential customers (society) and new technologies (scientific and technological knowledge) Opportunities can occur without the first inventive step Is an evolution of the linear model	In seeking stage new opportunities are raised considering changing needs imposed by the market, political pressures and competitors It incorporates context influences dynamically Its simplicity favors its conceptual adoption, but the lack of operational mechanisms affects practicality	Involves everything that represents value for the company and that can be traded at some point in the innovation process Stimulates the search for ideas and technologies from different sources and internalization Internalization can run with patents, know-how, prototypes, and other elements that represent an opportunity to gain value Incorporates all interaction concepts of previous models

As can be noticed, all models treat the opportunity identification, some more explicitly than others. However, there is a mixture between the idea and opportunity concepts. Several methods for stimulating creativity and generation of ideas, as proposed by King and Schlicksup [27] are known and can be addressed. But as discussed previously, not all ideas represent opportunities. Such models are generic, in order to operationalize them one can use several tools and systems. To bring a light uppon the opportunity identification aspects, it is valuable an investigation on the idea management systems.

3.2. Related works on innovation/idea management systems

On the following five studies and models for idea management that, in authors' view, make interference with the innovation models when identifying opportunities and/or may be used as starting point for the NPDP.

Barbieri, Álvares and Cajazeira [11] present a proposal for the idea management that incorporates the generation of ideas. According to Fiedler [28], the work of the authors focuses on suggestion programs or systems. Ideas about products, processes and business, new or modified, can come from both internal sources and external of the organization. External sources are customers, suppliers, competitors and others. The internal ideas source is the staff of the organization itself, as leaders and workers. The generation of ideas can be accomplished through methods such as brainstorming, lateral thinking and kinetics. The means to stimulate and capture the organization's internal staff ideas range from a suggestion box to ideas management systems, integrated into the global system of the organization and also to other specific management systems such as quality management, environment, health and security, among others [28].

Cunha presents a model for product ideas analysis and management to support the innovation planning [29]. According to him, the ability to innovate in product of any organization is directly related to a continuous flow of new ideas able to meet the opportunities of new products and technologies. However, the successful development of new products requires more than generate ideas. The author identifies the ideas management process can follow different logics according to the characteristics of the companies. Certain factors, such as: strategic definitions, process driving forms and organizational factors should be taken into account in defining the best way to manage the process [29]. Although the work addresses different organizational aspects, recommends known practices of creativity to obtain ideas and methods not focused on the problems that support them (opportunities).

Silva proposes an analysis and modeling of innovation management processes for the innovation management platform I9Source, currently under development at the Faculty of Engineering, University of Porto (FEUP) [30].The paper presents a set of references about the monitoring process and idea management, challenges and opportunities particularly to idea management processes. An important aspect of this work is the computational modeling of the processes involved and the detailed description thereof [30]. It is note that it is possible the computational application of concepts, but the author notes difficulty in this process. The focus is also given in the innovation based on ideas and some tools for creativity stimulation are proposed to operationalize their obtaining. However, when emphasizing some areas of information surveillance among the staff, it is believed that this process may lead to reviewers to identify new opportunities and ideas.

Freire provides an integrated system for idea management, challenges and opportunities to be integrated in I9Source innovation management platform [31], as well as Silva's work [30]. The proposal provides a detailed process model and a computer application. One aspect that differentiates it from the previous aproaches is the possibility given to the user to freely insert in the system, for further evaluation, what he or she believes to be opportunities and challenges, in addition to innovative ideas. However, besides this ability, the system does not map the stimulus methods to recognize these opportunities or challenges.

Fernandes presents a model for the acquisition of knowledge for identifying business opportunities in social networks [32]. The author cites the work of Kampa [7], and includes cognitive aspects of the process as a stimulus, but has a different approach. According to the author the growing traffic of data and information submitted by networks can contain the knowledge to feed the innovation process, specially with regard to opportunities identification phase. Thus, the author propose a model for acquiring knowledge available on prior knowledge of the entrepreneur and the existing knowledge on social networks. Part of the model includes the content analysis technique, the CESM model and CommonKADS methodology. The model is detailed on the tasks level, is broad and seeks to encourage the recognition of patterns that can be considered opportunities.

4. Discussion and final remarks

This research was limited to third-party material previously published and constitutes a basic review on the innovation models and systems and how they treat the opportunity identification. Specificaly if they do in a different way than idea generation. Few details on its mechanisms were found, however, it was found that some models explicitlly differentiates the search of opportunities and ideas. Some idea management systems allows problem related inputs to feed the inventive process.

The study does not exhaust the need to issue the operational details, especially regarding the mechanisms applied in the open innovation model. It is believed that this work fills its original purpose of composing a theoretical discussion about the innovation models and other related approaches on the opportunity identification. It is also noted that the theme, besides having branches on entrepreneurship and cognitive psychology research, is being addressed in researche on the area of knowledge management and innovation. The work of Freire [31] and Fernandes [32] show that the opportunity identification is not limited to the idea generation and that it is possible a computational aproach to explore the objective information available on social networks and pursued by the individual conducting the survey. Also, the I9Source system can be a starting point for further study.

Despite the findings and authors who support the terms differentiation, the biggest identified research challenges still reside on the ontology. It is difficult to elaborate on models and proposals when authors use terms without clearly defining them.The Fuzzy Front End of NPD still represents a complex problem to deal with, one that demands higher thinking. As complexity in engineering is often treated by segregating problems on simpler bonded portions, the same logic seems to be valuable on the idea/opportunity research. This could bring the problem to a malleable level while one gathers ability to comprehend on its nature. The Baron propositions (section

2.1) to opportunities identification still seem relevant but tacit in the innovation and NPDP models [12].

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Template for Supporting Welding Design on Aluminum Vessels

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Abstract. The use of aluminium hulls has advantages such as versatility in achieving complex shapes, lightness, strength, durability and it doesn't present corrosion issues nor embrittlement by temperature. When designing aluminium hulls the designer prioritizes welding as a major joining method. However, the aluminium welding process is complex, therefore the requirements involved in the manufacturing are critical. Furthermore, it is noted that when the design is performed on small and medium-sized vessels, these requirements are not adequately considered early in the design process. This fact is made worse when considering the product life cycle, generating problems such as redesign of the product, increasing manufacturing time and material waste. This paper proposes a design Template to assist obtaining the design specifications of aluminium vessels in the early stages of product development. The Template is based on the product life cycle and takes into account the general and specific attributes in order to generate a list of design rules, recommendations, best practices and solution-solving principles, which were established based on the literature and on professional experience. The outcome of the Template is a set of information which are available throughout the matrix. In order to improve the result, surveys and interviews were conducted with experts in the field. The main advantages of the use of this tool in designing a vessel are: i) to enhance knowledge management since new information (knowledge) can be added in the matrix cells, as the shipyard acquires knowledge; ii) to facilitate the integration of designers with different technical areas of a shipyard; iii) to reduce the design and manufacturing time of the vessel; and iv) to reduce product development costs, since waste is reduced.

Keywords. Design, Template, Welding, Aluminium

Introduction

The aluminum applied to shipbuilding has numerous advantages and its use is widespread all over the world, especially in countries with a strong market for recreational boats like the USA and the Netherlands, where aluminum is widely used in the construction of motorboats and sailing yachts of all sizes [1].

The main advantage of aluminum compared to steel is resistance to corrosiom. Available in a large number of blade's thicknesses obtained by rolling and extrusion, besides automated cuts for mounting boats and CNC machining (Computer Numeric Control), the application of aluminum in the shipbuilding industry is promising because it minimizes the difficulties in manufacturing complex hull geometry. This trend can be

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observed in the growing market of aluminum. According to data published by the Brazilian Aluminum Association (Abal), there was an increase of 5% aluminum use in 2013, with a large participation in the transport sector with 7.4% growth between 2012 and 2013 [2].

In Brazil, the market is potentially favorable, especially in the northern region. Besides the sustainability due to easy recycling of aluminum (which does not occur in composites), the material is distinguished by its durability and a good reason between cost and benefits. The immense river basin in the northern region is essential for the transport of the local population in everyday life. According to Antonio Teles, these sectors evolve driven by the development of the free trade area of Manaus, which consumes metal in increasing doses, particularly in construction and shipbuilding [3].

In addition, at least 60% of small and medium-sized vessels are produced using aluminum. The result is 450,000 vessels currently anchored in yacht clubs, fishing clubs, garages and marinas throughout Brazil. Every year, over 10,000 aluminum vessels are produced thanks to an average growth of 10% per year, from recreational boats to sports [4]. Much of the growth of aluminum vessels occurs by public preference for tougher boats, which do not break with impacts and have increased durability. These boats can reach a percentage up to 95% of aluminum in its structure, as some fishing boats currently found on the market, which can reduce the final weight of the vessel in approximately 30% [5].

In the construction of these vessels, welding is a fundamental and critical union process. According to Stump and Vatavuk [1], the welding can be applied to shipbuilding industry nowadays only because the development of new methods and modern welding equipment of inert gas welding, applied to plates with thickness from 2mm. The aluminum alloy welding usually use argon gas to prevent the formation of alumina, which would hamper the penetration of the alloying metal, therefore, decrease the welding quality. For thicknesses above 12 mm, it is recommended to enrich the gas with helium, taking care with cleaning and preheating up to 75 degrees Celsius [7].

For the shipbuilding industry, two welding techniques are used and are known as TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas). TIG welding is used for thin blades and some other fine weldings. The welder uses a rod of alloy metal manually, this rod reach its melting point by an electrical arc from a tungsten electrode. On the other hand, MIG welding is the most widely used technique because it is faster for large constructions. The melted metal is automatically deposited by a gun that also diffuses the argon (with or without added helium) in the zone to be welded.

According to Nasseh [6], the construction of aluminum boats is still a procedure recommended only for experts because extensive knowledge of techniques of welding and fabrication is required. The most common defects arising from errors of operation can be the lack of penetration, lack of fusion, inclusions, porosity, etc. [1]. Furthermore, the operations employed in welding should be defined and respected in order to limit distortions, whether local or general. Depending on the thickness of the aluminum and the length of welding, the difference of temperature can cause distortion of several centimeters along the hull.

From the above, it is clear that the growing use of aluminum and its alloys in the shipbuilding industry requires a larger study of the methods and welding recommendations. The lack of technical knowledge can cause enormous damage to shipyards and damage the positive reputation that aluminum has in the market. Given this situation, this paper seeks to define a methodology for creating recommendations for the design and construction of aluminum vessels in the welding process.

1. Background to the Proposal of the Template

In view of the increasing production of aluminum vessels, the more necessary is technical knowledge, enabling sustainable growth of this sector in the shipping industry. The literature, in general, still lacks clear recommendations for the design and execution of welding aluminum alloys applied to manufacture hulls.

There is currently on the market a wide range of vessel types using aluminum in its structure. The main examples are fishing boats, sailboats, yachts and sports boats. Because the high exigency of those users, a high quality product is essential, not only because customer demand, but also because the performance required of the vessel is higher. The applied aluminum percentage varies according to the type and purpose of the vessel, reaching 95% for some fishing boats.

The shipyards performing that sort of process have usually harmful environments that are exposed to weather conditions such as wind, humidity and salinity. In contrast, the quality level required in the process is high. The workforce has become more specialized with the increasing number of trained professional available to work in the shipbuiling field, however, there is still some shortage in the sector.

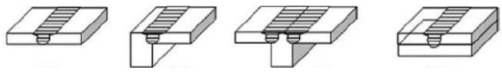
A key point in the development of aluminum vessels is that many design requirements show dependency on each other, resulting from the multidisciplinary and interdisciplinary approach of the information from the knowledge of vessels experts. In practical terms, this dependence results in trade-off solutions for product design, which do not always produce the desired result, since the design requirements are not covered in their fullness simultaneously. In other words, because of the difficulty of interpreting design requirements in a integrated manner, experts end up using their knowledge in isolation, setting solutions that do not end up the most appropriate for designing aluminum boats.

When dealing with the product development process, two types of knowledge can be used. Explicit knowledge and tacit knowledge. According to Nonaka and Takeuchi (1997) [14], explicit knowledge are those structured and capable of being verbalized. It corresponds to part of the knowledge that can be expressed, stored and shared in documents, books, worksheets, systems, etc. Tacit knowledge are those inherent in the people, such as the skills they possess. They constitute the knowledge that is not structured and can not be registered and/or easily transmitted to others.

In this context, it is observed that:

- The rules, strategies and solution principles used for aluminum boats projects, the explicit knowledge, are quite generic and do not provide project specific situations.
  - Design rules indicate the proper way to perform an action in order to achieve a specific goal, being established through proven knowledge by experts in the field. These rules are the explicit knowledge of these experts;
  - The design strategies indicate the best conditions or favorable paths in order to achieve a specific goal, being established by the expert, through the observation of manufacturing practices. These strategies are the tacit knowledge of these experts;
  - The solution principles are graphical representation of explicit and tacit knowledge of experts.

Table 1. Example of rule, strategy and solution principle.

Design Rule for Welding	Ensure that it is used compatible adition material, preferable used MIG process.
Welding Strategy	To reduce plate distortions plan the joining ahead, weld small segmented portions within a good distance from one another. Deposit less heat by depositing less material.
Solution Principle	

- Incorrect use of this knowledge may result in negative effects on the quality, cost and functionality of the product. Yet, the failure to fulfill a design rule, in some cases, can mean a better solution for product design;
- Project specifications involve assigning values to design requirements, which is performed subjectively as usually occurs based only on the experience of the product development team (tacit knowledge). As the design tools do not support these features, specifications have been formulated without considering systematically the knowledge of aluminum boats development area, which may cause problems in the stages of conceptual design, preliminary and detailed product.

As stated the welding process of aluminum vessels is complex and the knowledge of experts is fundamental. In this regard, the definition of recommendations and best practices for the design and manufacture of aluminum vessels is important to:

- Consider and evaluate the knowledge of experts in an integrated and systematic manner;
- Assist the development of concept (shape) of the product, which is determined considering restrictions associated with the use of the product, the manufacturing process, the rules, the recommendations and principles of typical aluminum product design solution;
- Facilitate the evaluation of the technical and economic feasibility of design alternatives, considering as an integrated manner the parameters associated with the project, processes, mold and injection material and simultaneously possible approaches costs and the level of abstraction of information.

In short, considering the above, there is the necessity to have the means to apply this knowledge effectively and consider the particular circumstances of the project.

2. Proposal of Design Template for Aluminum Hull Welding

The Template proposed is based on the approaches by: i) Ferreira [15], which seeks to integrate QFD tools - Quality Function Deployment - and TRIZ - Theory of Inventive Problem Solving - to assist the definition of project specifications of injected components; and ii) Fonseca [8], which presents a system for assisting the setting of industrial products.

The proposed model is shown in Figure 1.

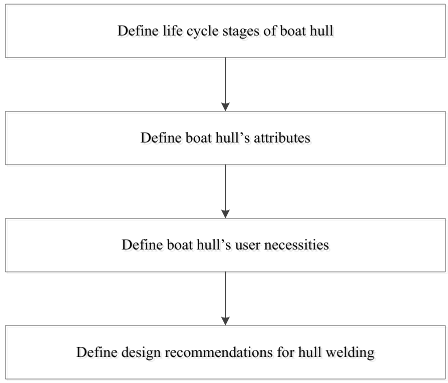


Figure 1. Proposed model to define the design recommendations.

Next, each of the steps proposed will be carried out.

2.1. Definition of life cycle stages

The identification of a product's life cycle is important, particularly to define the ones involved in each stage of product development. As shown by Back et al. [15], based on the work of Fonseca [8], and exposed in Figure 2.19, the product life cycle includes the stages of planning, manufacturing, assembly and packaging, transport and distribution, sale, purchase, use and maintenance, decommissioning, disposal and recycling.

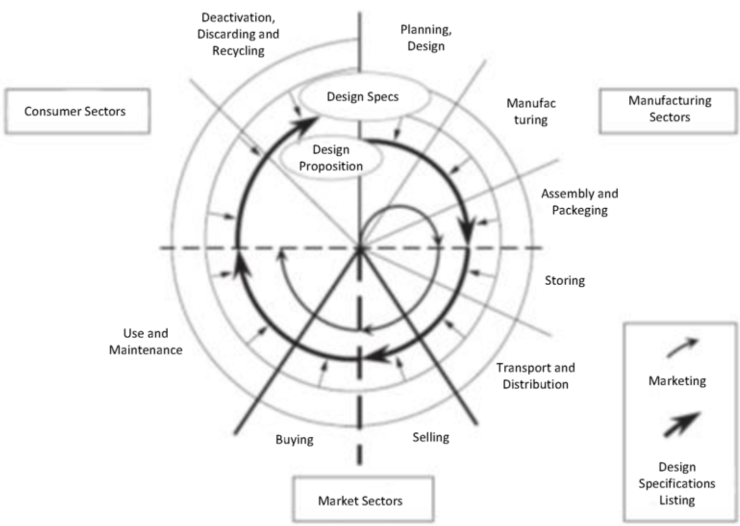


Figure 2. Stages of life cycle of a product (Back et al. [15] adapted from Fonseca [8]).

In the case of the shipping industry, those involved are users, shareholders, company departments (design, product engineering, manufacturing, assembly, sale, distribution), suppliers, after-sales team, among others.

2.2. Definition of product attributes

To define the design requirements, Fonseca methodology [8] was used. The product basic attributes represent competitive factors defined by the product properties that will be evaluated by the market and the customer, while the life cycle attributes are those corresponding the product phases throughout its life. Considering the properties of an aluminum shell, the most relevant attributes are shown in Table 1. They are: function, ergonomics, safety, normalization, aesthetics and reliability. And, the life cycle phases are: design, manufacturing, mounting, use, function, maintenance and deactivation. This matrix received the name of User Needs Support Matrix.

2.3. Users needs definition based on expert consultation

Related to the product needs matrix, a questionnaire was developed and applied to four experts from the welding area. The answers provided by the experts were able to generate the specific needs of the product throughout its life cycle. These needs will be used, later, to elaborate a matrix to support the conversion of user requirements in design requirements. The main requirements raised by experts are represented in Table 2.

Table 2. Raising support of users' needs Matrix, adapted from Fonseca [8].

LIFE CICLE PHASES	PRODUCT ATTRIBUTES				
	Function	**Ergonomic**	**Economic**	**…**	**Reliability**
Project	Guarantee the parts performance.		Reduce cost.		
Manufacture	Prioritise modular mounting structures to be used in different constructions.				
Mounting		Focusing on the mounting facilities.	Choosing commercial components.		Minimizing the components number. / Limiting components with high dimensional accuracy.
Use					
Function	Ensure balance between the parts and the use of compatible materials.	Ensure access to parts.			
Maintenance	Minimizing maintenance.				
Deactivation			Use of easily recyclable materials.		

2.4. Elaboration of design recommendations' Matrix

The design recommendations' Matrix intend to guide the project team in the selection and determination of metrics and indexes of target quality for the unions design specifications welded in aluminum hulls. This matrix being grounded in this life cycle has brought the users needs of each phase, the specific attributes and design requirements to achieve the desired quality. The design recommendations, given by the crossing of the project requirement and columns of the matrix, reflect the attributes of the product life cycle in order to guide and facilitate their contribution during project execution (Table 3).

Table 3. Design Recommendation for Life Cicle Matrix.

			Basic Attributes				
User Require-ments	**Specific Attributes**	**Design Requirements**	**Manufac-turability**	**Market-ability**	**Usability**	**. . .**	**Reliability**
RU_1	Geometry	RP_1	RC_{11k}				
RU_2		RP_2	RC_{21k}				
...	...	...			...		
RU_i		...					RC_{ijk}

The first column brings the users needs from the User Needs Support Matrix from Fonseca [8]. Each set should be categorized to attend their respective specific attribute as noted in user requirements conversion matrix in design requirements, also Fonseca authoring [8]. This division and organization tries to instill in the project team the need to be measured these requirements for the quality to which they are attached, since that, during the project implementation is extremely important to have in mind its origin, thus avoiding unnecessary questions and revisions of previous phases.

The columns guide and lead the project team throughout the life cycle. In it are willing attributes of the life cycle: manufacturability, condition, technologies and features that the object to be manufactured must possess to be capable of manufacturing according to the existing processes and methods on the factory floor to which the project is intended; rideability, the characteristics, conditions and technologies required to mount the component in space, which was designed to occupy; transportability, to be possible the shipping, while maintaining its integrity and quality; functionality, integrity and quality aspects that would give conditions for the elements bearing the load and environments that should be designed; maintainability, conditions, characteristics and technologies used to provide adequate maintenance, thus ensuring its reliability; recyclability and disposability, holds the relevant information for the product to be dismantled and for the best possible way to its disposal and recycling.

The design recommendations are derived from the specialized literature and the best practices of the company's knowledge management to the intended design. They are allocated at the lines intersection with the matrix columns above and are organized in the vector form, acting as a file drawer. Eventually the company will specialize in solving that hall of user requirements, providing its products with the desired quality by users as the main activity.

It is noteworthy that the project team should focus its efforts together with the users hull at all phases of the life cycle, attempting to mount this matrix in project meetings. Besides being also important that the other entities involved in the project also keep their processes history and best practices to feed the matrix. In this way the project team can select the design recommendations that best suit their design issue.

3. Proposed Template Application Example

The construction of the matrix provides some thoughts for its use. The first concern is with the importance of each inserted recommendation. The reported information will be used by the designer several times, so any bad reference should be discarded in order to prevent a very costly errors chain to the yard (Table 4). The same goes for its use in day-to-day. One of the main intentions of this tool is that it is used in design management information, continuously enriching it with more information extracted from errors and trial of shipyard everyday. Shallow or dubious conclusions should be avoided so this tool can bring security throughout the design and construction of vessels. Therefore, discussions about any change should be encouraged by all involved.

Table 4. Design Recommendation Matrix Example for Welded Joints in Aluminium Hulls

Users Requirements	**Specific Attributes**	**Design Requirements**	**Basic Attributes**			
			Manufacturability	**Marketability**	**Usability**	**....**
Guarantee the performance of the parts	Geometry	Welding position	Torch Conduction: attack angle, tilt, performing weaving 9			
		Weld Bead Aspect	Standards AWS D1.1/DNV	Use MIG welding or pulsed or goticular to obtain weld beads with better look [9]		
	Signals	Weld beads aspects	Non-destructive testing: Ultrasounds Welding through pass aft technique			
	Quality	Number of defects	Use suitable filler material to the base material according aluminum class. Using pure argon		Eliminate the presence of hydrogen / oxygen during welding [9]	
Reduce cost	Geometry	Welding position	Always try to use the flat position for welding			
	Material	Cost of adding material	Prioritize rods / most common wires commercially: AWS 5.10 ER4043/ AWS 5.10 ER5356 [11]		Reduce time in stock of the electrodes and the material used [9]	
	Signals	Welding Process	Prefer goticular welding using simpler equipment	Use friction welding to reduce welding costs in large platings [12]		

		Number of passes	For joining sheet from 1.2 to 50mm in a single pass use friction welding [12]			
Ensure crew safety	Material	Reliability of the filler material	Use suitable filler material to the base material according to the class aluminuio			
	Estability	Cord continuity	Use friction welding to minimize distortion [12]. Perform the welding in a single pass. Be careful with external air currents [11]			
	Quality	Number of defects			To minimize lower penetration than adequate, increases the supply of energy	
		Deformation of the welded joint	Use the tab. 5-3 "Permissible Alignment of Butt Welds (ABS)" to find alignment tolerance. Use friction welding to minimize distortion [12]	Use MIL-STD 1689 Tolerance to minimize distortions union [12]		

4. Conclusions

Some conclusions can be drawn from the generated matrix by responses from experts. First, there were not raised needs for the aesthetics of the weld bead generated, as the phase of "use" in the life cycle has no necessary recommendations. In addition, there is the suggestion of the use of modular structures, capable of being used in more than one operation. The difficulty of this process is found in yards that has poor reproducibility of its products, requiring even greater flexibility for these structures. Another factor is the security that the user demand for himself and the crew, this requirement is not only important, but also a result of standardization requirements and, also, function. As for the economic aspect, it is noteworthy that unlike other recommendations, *e.g.* respect standards, it is an optional feature, varying according to the product offered to the customer. Finally, note that there are considerable number of recommendations that encourage a care in maintaining a simple design, facilitating welding and reducing the number of components.

Looking at the matrix as a whole, other observations can be made. It should be noted immediately that not all spaces are filled, however, this is not a factor that invalidates the construction of the matrix, because only the most important requirements should be cited. In all, 14 mentioned requirements, despite the diversity of each cell of the matrix, none of the requirements excludes any of the others. This fact allows the unrestricted use for the matrix construction of the project recommendations.

It does not escape the attention the fact that this is an innovative tool to organize and support the process systematization of getting design specifications proposed by Fonseca [8], since the exploration in the literature on project management and product development does not point systematic in the same form and content. However the population of these crossings becomes a harvest of few and for few holders of knowledge. It is an iterative and knowledge management task that the project team and the institution to which they belong must keep your organism processes, with the target point the record of valuable "lessons learned".

In short, with the Template, it is expected to:

- provide a wider range of design information to minimize the high level of abstraction and maximize the number of available data considering the multidisciplinary and interdisciplinary knowledge of experts;
- generate information to guide the phases implementation of conceptual design;
- consider the dependence of the design requirements in an integrated manner and seeking, mainly, solutions that address these requirements in their entirety, therefore, thus avoiding whenever possible, the call compromise;
- help define design constraints;
- provide means to employ the tacit and explicit knowledge of experts in a systematic and integrated way, and considering the particular circumstances of the project;
- identify areas in which greater efforts (time, technical resources, financial resources) should be concentrated.

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TRIZ Application in Rolling Armored Safety Car Glass

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Abstract. Corporate competitiveness requires products and processes increasingly developed. The automotive sector hosts a large number of complex processes and increasingly produce more with fewer resources and less time to perform. The Russian TRIZ methodology enables you to create or develop solutions through the call "Inventive Engineering". Therefore, this article aims to present a creative solution to fixing armored glass slides through TRIZ technique. The research was carried out in an industry leader of safety glass in Brazil. In the end, it was found that the solution integrated with the mechanical material properties of the product through a creative and innovative solution.

Keywords. TRIZ, Safety Automotive Glass, Creative Solutions.

Introduction

In Brazil and in the world, science and technology, are part of the production chain that moves the economy of nations. Therefore, there are many researches and studies around techniques, models or projects that allow leverage the development of organizations . Currently , the term innovation is increasingly present in companies like instrument protagonist of competitiveness and market leadership [1], p. 194. If innovation is so important, this work has the purpose of giving light on a form of technology that abstracts innovative ideas from the analysis of existing solutions. In this sense, this article presents a principle that may or may not require a considerable amount of financial resources or specialized human capital, but a distinct ability to solve problems by means of the "Creative Engineering" developed on the principle of TRIZ. Because TRIZ "can be used in a number of different ways. An overall process Enables users to systematically define and Then solve any problem or opportunity given Beheerder situation" [2], p.1.

The TRIZ can collaborate on optimizing the manufacturing productive sector booming in Brazil , the armored vehicles market. Shielding according to the Brazilian Association [3] the year 2011 hit another record production with 8,106 armored vehicles. This number reflects the demand of the people by armored cars, indicating the increase in crime and urban violence. The growing demand implies also in increasing production, both in quantity and in quality.

Against this background, this article presents a study of the process of manufacturing of automotive safety glass. The armored glass are manufactured in complex industrial processes that require a high degree of specialization and quality,

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especially at the end of the rolling process. Given the complexity of manufacture, it will use the principle of TRIZ to develop a creative solution to a fastening system of the armored glass sheets during the fusion process performed in an autoclave. Therefore, the research presents the methodology to be used in this research, after this introduction. Following the review of the literature is presented that will support the technical application in the case study, the last section of this article.

1. Methodology

The research methodology seeks to define and structure the way research for consistent construction of knowledge. Therefore, this article follows the ways of the classification proposed by Gil [4] as applied research, it has the interest of generating knowledge for application in practical cases to try to solve "real and immediate needs" [5], p. 152; and exploratory objective, investigating a real experience of the problem facilitating their understanding and building ideas for the study. The case study method enables a unique and in-depth look researched unit, in this case a study in a multinational industry of automotive safety glass . Whereas these reasons, the method of this research can be demonstrated by Figure 1.

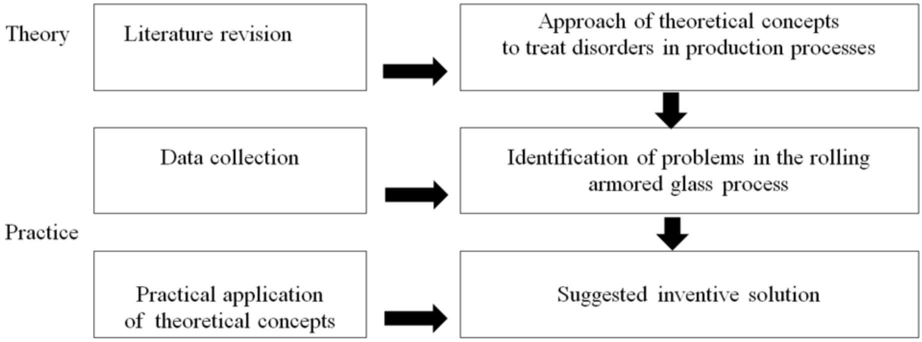

Figure 1. Outlining the research methodology.

2. Theoretical framework

2.1. TRIZ

The globalization and globalization of the economy are prompting businesses to a constant and innovative development. The use of resources, especially financial, are active organizations reserve in search of the development of differentiated solutions in their products or processes. Facing these challenges , business competitiveness can be based on different methods of operations, working through creativity. Manufacturing issues can be dealt with creative ways to minimize production costs and ensure quality standards of its products and processes, with the use of systematic engineering procedures [6]. With this idea in the 40s, the Russian engineer Altshuller developed the principle of TRIZ, a Russian acronym of phrase that can be translated as Theory for Inventive Problem Solving. According to Savransky [7], TRIZ is "a systematic methodology, oriented to the human being, based on knowledge, to the inventive problem solving" that can be illustrated in Figure 2 below.

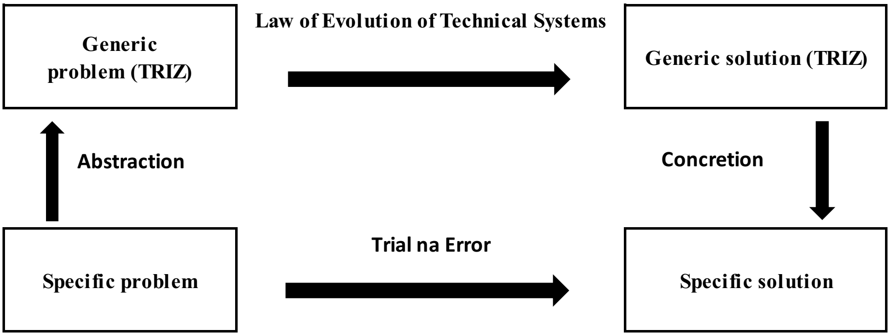

Figure 2. Methodology TRIZ, Source: Li et al. [6].

The knowledge combined with a systematic analysis can assist in generating the appropriate solution to the kind of worked problem. The study on a search deviation frame it in a kind of "standard issue " to identify a resolution standards-based solutions that can ultimately define a particular solution . The preparation of the solution of the fundamental concepts of TRIZ : ideality , contradiction and resources. Since this theory has its pillars guided by idealism, emphasizing creativity and innovation [7] .

To Altshuller, the evolution of technical systems occur in the direction of increasing ideality. In fact, the solutions are researched and developed in order to equate the "desire" (need resolution) with an "undesirable" factor (resources used). These elements are considered and presented in relation to ideality, as proposed by Altshuller [7]:

$$\text{Ideality} = \text{desired} / \text{unwanted}$$

In this sense , reducing the "unwanted" can raise the ideality factor active, causing the solution to near the "ideal", as stated by Malkin and Malkin [8]. More simply, the more evolved is the system, or close to ideal, the lower the impact on the market [9]. From the foregoing, it can be understood that the ideality depends on the actions carried out around the desired factor at the same time influence the unwanted factor, showing the "contradictions" surrounding the issue. In fact, conflicting factors may exist in the scenario analysis that may represent limitations or opportunities.

By contradictions, it is understood as paradoxical situations where an improvement action can cause degradation in another part of the system. The principle of TRIZ considers that a technical problem is defined by contradictions, technical or physical. Inconsistencies would techniques improve a characteristic at the expense of another factor improvement. Physical Contradictions are elements inherent to the product that contrast in their function or development [7]. These types of conflicts are considered the so-called engineering parameters (PE), another existing field in the TRIZ methodology. The PE group 39 conflicting characteristics of a technical system with its sheltered solutions concept called Inventive Principles (PI). The solution of the problems can be articulated by all 40 fundamentals of IP relating to the PE method called Matrix of Contradictions (MC). MC correlates PE (in columns) and contradictions (in lines). The intersection of row and column shows the IP more used to solve the contradiction, presented in order of occurrence according to a survey conducted by Altshuller, represented in Table 1.

Table 1. Contradictions matrix stretch, adapted from Savransky [7].

PE ↓ Contradiction →	Manufacturing quality (29)
Ease of operation (33)	PI 1,32,35,23

According to the figure, the IP that could solve this contradiction would be the PI 1 (Segmentation), 32 (color change), 35 (change of parameters and properties) and 23 (Feedback), in that order of resolution respectively. The MC has principles that can help in troubleshooting already considering the technical or physical contradictions of the object under study.

And the last fundamental concept of TRIZ are resources that can be understood as all elements in a technical system which can be used to generate inventive solutions [9]. In addition to these techniques, the principle of TRIZ is home to other tools like Evolution postulates or ARIZ that are not addressed in this research. All these concepts and methods are recognized, with applications starting from the engineering, architecture to the field of administration [10], p.64.

2.2. Armored laminated glazing

The discovery of glass is very old and historians recorded use since the Egyptian era. Artistic object for residential use, the glasses are being increasingly used for different applications. Thus, this product has been the subject of intense research to develop their mechanical properties such as hardness, compression or flexibility. A special property that has been developed in glasses is their resistance to high impacts. As the glass has high application in transport, they must have the ability to withstand high shocks. In urban vehicles is no different as the cities experience a fenced scenario of insecurity [11], citizens seeking to protect in their time of displacement with the use of armored vehicles. These vehicles are equipped with bulletproof glass, which are security products. This product has at least two or more beams of laminated glass with polycarbonate layer.

In the manufacture of armored glass plates are joined by exposure to high temperatures and pressures, usually around 140 0C and 14 bar in a device called an autoclave to ensure that there are air inlet between the blades that make up the laminated glass [12]. The material most widely used laminated glass among the layers is the polyvinyl butyral (PVB), considered viscoelastic, i.e., their properties may change as exposure to temperature and pressure. For this fact, the development of laminates with PVB glass manufacturing processes is a challenge for manufacturing engineering [13], p. 2. This and other structural elements form high-capacity glass, without, however, eliminating a possibility of rupture. As a main feature, even though the glass is broken, do not occur laceration or tearing, or it withstands the crossing, stretchable up to five times its original size. This deformability enables resist ballistic impact expelled from the firearm, which is a result of the absorption of the kinetic energy of the projectile on the glass slide. That is, while the glass has a high hardness property, it must have flexibility and toughness against impact. The development of these properties favor the industries of glasses and materials that are used in armored structures for a more consistent and sustained lightweight composition.

3. Case Study

This research was carried out under market industry leader in automotive safety glass , the company American Glass Products in Brazil, in São José dos Pinhais, in Parana state.

The process of manufacturing reinforced glass passes through various stages , and final stage involves laminating the glass . Due to engage variables (temperature and pressure) that influence all previous manufacturing processes and influence the final quality of the glass lamination process of the glass was selected as object of this study. Thus, only exploiting the lamination process after the cutting and fitting of the blades that comprise layers of reinforced glass , the glass is deposited on a metallic platform (rack) provided with hoses for temperature and pressure control, shown in Figure 3.

Figure 3. Metallic platform.

Carried out the placement of the windows on this device, it is placed in the autoclave for laminating the glass. This stage is that there is a problem handling the glasses on the platform due to the condition of support and fixing the glass (Figure 4).

Figure 4. Fixing system for glazing in an autoclave.

The displacement of the product does not occur by mechanical inefficiency of the probe but the interference of the conditions imposed in the autoclave . This finding was obtained by the survey conducted by the engineering team of industry processes. Changes can cause dimensional changes of glasses.

Using the principle of TRIZ, followed by the procedure of analysis shown in Figure 5.

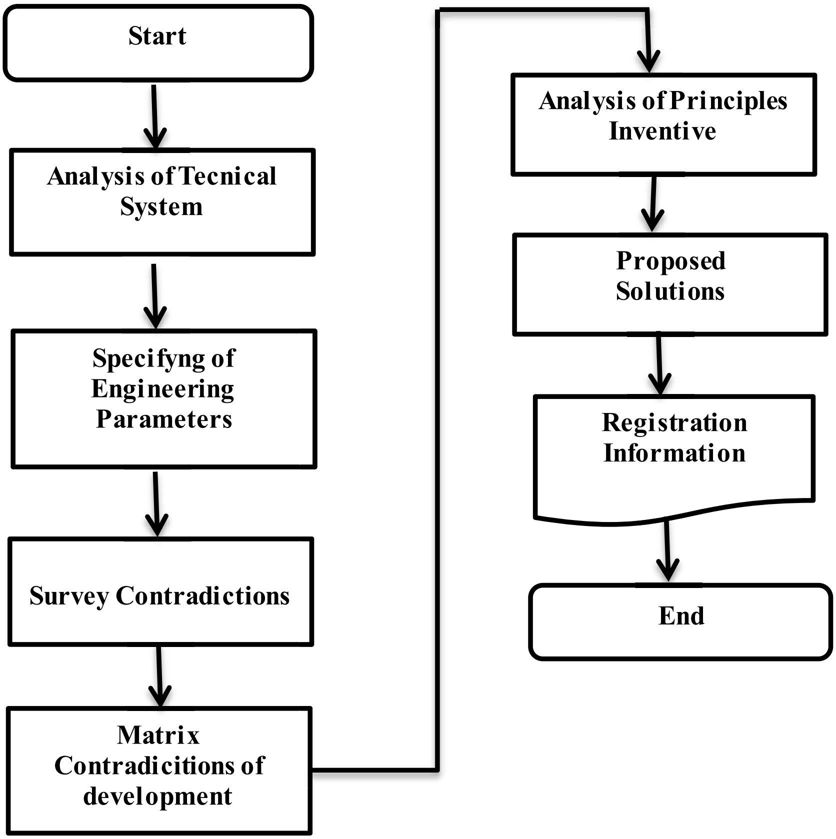

Figure 5. Flowchart analysis of the problem.

Thus , the first step of the flowchart is constructed , the determination of ST:

- Technical System Name (ST) : System of rolling armored glass .
- ST function: Perform rolling armored glass .

ST main elements: metal rack (device) , autoclave (equipment) and safety glass (products). The components that make up the subsystems enables to understand and identify possible failures involved in the ST thus Figure 5 shows ST, subsystems and their functions:

Table 2. Components ST.

Technical System (ST)		
Subsystem	**Description subsystem**	**Subsystem function**
Rack	Metal structure with cots , claws and pulleys	Crib: glasses support; Claws : fixing glasses ; Pulleys : wheels for the rack
Autoclave	Coated Chamber of thermal resistances and thermal products	Thermistors : Heating; Pipelines : pressure flow
Armored glass	Set glass slides	(product) passive element

ST Functional description : Initially the glass are deposited on the rack and are fastened by a fastening system . The following are placed inside the autoclave where they are subjected to a temperature of 1130C and a maximum pressure of 10.2 bar during a time cycle. At the end , the rack is removed from the autoclave and is in segregated area for reestablishment of ambient temperature to then be sent to the next job. Procedure to assess:

- Variables present in the ST operations : the subsystem components.
- ST characteristic to be improved: fixing the glass to prevent displacement of the product during the rolling process .
- Ideal Final Result (RFI) expected: adequate fixation of glasses with ease of operation and efficient lamination warranty.

Once defined the object of study , the elements that operate in the Subsystems shall be specified, the engineering parameters (PE), which allows approach and understanding of interference in the process. Thus, the second step shows the engineering parameters (EP):

- Object composition stability ;
- Duration of the operation;
- Pressure and temperature;
- Ease of operation ;
- Manufacturing precision .

Following the methodology of TRIZ , the search for solutions is guided by characteristics of the ST and conditions which sometimes act in a different way in the problem, the Contradictions calls (C). Therefore , treating the C can improve aspects of a feature, keeping other within acceptable levels , and in our case the C are:

- Stationary object area ;
- Waste of time;
- Object composition stability ;
- Complex device .

Based on PE and C , left to the verification of these criteria by the Matrix of Contradictions (MC) to identify Inventive Principles (PI) indicating solutions to these factors. Figures 6 , 7, 8 , 9 and 10 show the MC of each foot link and C:

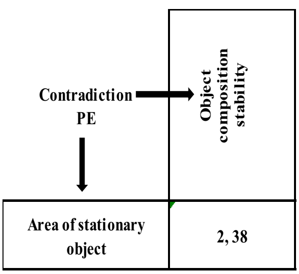

Figure 6. MC A.

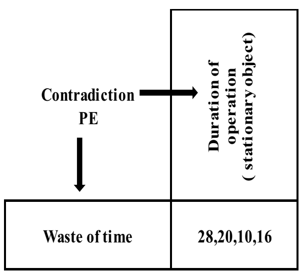

Figure 7. MC B.

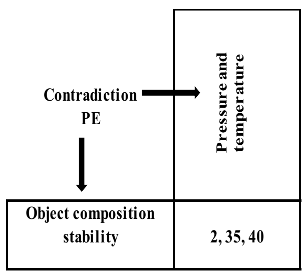

Figure 8. MC C.

For MC A, the PI are:
- 02: Removal or extraction
- 38: Use strong oxidizers

For MC B, the PI are:
- 28: Substitution mechanical means
- 20: Continuity of useful action
- 10: Prior Action
- 16: Partial or excessive action

For MC C, the PI are:
- 02: Removal or extraction
- 35: Change parameters and properties
- 40: Use of composite materials

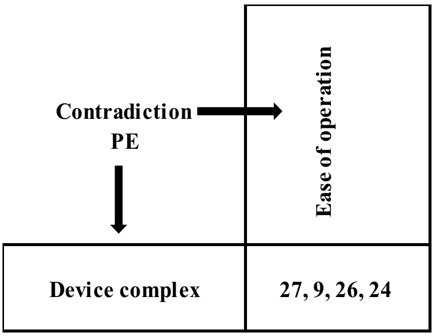

Figure 9. MC D.

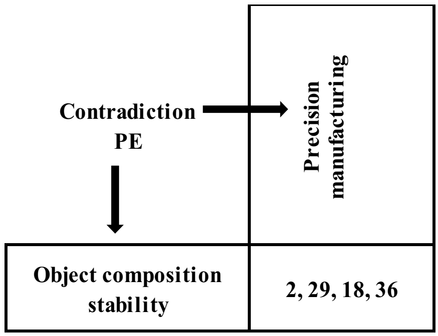

Figure 10. MC E.

For MC D , the PI are:
- 27: Use and Disposal
- 9 : Prior Compensation
- 26: Copy
- 24 : Mediation

And finally, for CM and the IP are :
- 02: Removal or extraction
- 29: pneumatic or hydraulic construction
- 18: Mechanical vibration
- 36 : Phase Change

The analysis of the results of the MC, it is observed that the common IP to all PE is the principle of "removal or extraction" in this way, it should be a key feature that should be treated. This idea ensures that a solution based on IP "removal or extraction" may act simultaneously on all other issues. Another PI considered important would be the IP 35 (change of parameters and properties) and 40 (Use of composite materials) due to the specific characteristic of the armored glass. Thus, the context of the solutions before the PI would be:

PI 2: fixing system that facilitates the release of the part after the process. At the same, it must have consistent ability workpiece clamping to ensure precision rolling, and hence manufacturing precision (PE "precision manufacturing").

PI 35 and 40: Whereas the intrinsic characteristic of the material of the glass must be hard, yet flexible to absorb ballistic shocks, the solution would be to use a system to support the glass that allows absorbing glass contractions during exposure at elevated temperatures and pressures within the autoclave.

In this sense, the proposed solutions are:

- Semi- mobile fasteners : supporters with adjustable drive course for placement of part of the device . The piece should have a graduated display for pressure regulation and support on the glass (knob equipped with torque wrench). After the process the system would be disconnected to remove the piece. This idea would meet the PI 2 .

- Coating of the support with soft material for expansion and glasses clamping pressure . At the same time , this material should be capable of withstanding variations in temperature and numerous cycles of operation (process repeatability) . This solution would meet the IP 35 and 40 .

Due to the intrinsic characteristics of the glass, the hardness and flexibility, it is important to refine the specificity of attachment of cladding to meet this property of the laminated glass. As a suggestion it would be appropriate to use a soft compound [14]: the Elastomer Ethylene Propylene (EPDM) . It is a synthetic elastomer and resistant to work temperatures ranging from -20 ° C to + 140 ° C. Is an elastomer which can be combined with other elements, enabling working under high workloads. For example, the mixture could be used known for royaltherm, developed and marketed by the Uniroyal Company.

Another proposal would be the use of the polynorbornene compound. This material is a high molecular weight elastomer and easily used with other elastomers such as EPDM. It has composition capabilities with other elements allowing withstand up to 5 shore A (hardness) and excellent mechanical strength and resistance to water and oils. This elastomer has wide application in the automotive industry, however, it has heat resistance up to 90 ° C and should be combined with other materials to increase their resilience to exposure to high temperatures and pressures.

The final step would be the registration of the proposed solution, this stage is typically performed by engineering processes with any survey, mapping and description of the solution so that its implementation is applied. After its implementation, should be made frequent monitoring by the same engineering team to check the consistency of the activity. Another important point to consider would be to draw up a record of actions taken and held for future composing a repository of "lessons learned" that can be applied to similar problems or replicated to other plants of the plant .

4. Final considerations

The study demonstrated the applicability of the TRIZ within a manufacturing problem suscentível different variables. The technical system involving problematic, home equipment (autoclave) which has great action on the end product, however, the inventive principle pointed oriented solutions for the operation of the process and not to the autoclave. In this sense, the resolution focused on the process and other variables on the problem. The pooled analysis of inventive principles allowed to present an integrated solution with different engineering of parameters, allowing also optimize investments to solve the problem. Treatment of contradictions evidenced in solution that combines the mechanical process fixation with the glass material properties. It would stress the importance of the final stage of the study consolidation, with the record of problem solutions that can give light to the principle of ideality where the repository solutions facilitate the search for desirable solutions in a shorter and faster time frame as demand dynamics of organizations around creativity and innovation.

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Design for Sustainability in PSS: Evidences of QFD-Based Method Application

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Abstract. Nowadays companies are pushed to offer solutions with new functionalities, higher performances, lower environmental impact, lower cost, and high usability for final users. In this context, the concept of Product-Service System (PSS) represents a valid way from manufacturing firms to evolve their market proposition, reduce impacts of their processes, and satisfy the customers' needs. However, the design of PSS is still difficult, due to the lack of structured methodologies and evidences of the benefits connected with their adoption. The research adopts a systematic QFD-based methodology and demonstrates its validity to develop high sustainability PSS solutions. The case study focuses on the definition of a new PSS for green roofs: two groups of students, using respectively traditional methods and the proposed QFD-based methodology, were involved. The two PSSs conceived were evaluated in terms of outputs supporting the design phases and sustainability impacts. The case study results demonstrated how the adoption of a systematic method allows developing more business-oriented and more sustainable PSS in respect to traditional methods.

Keywords. Design for Sustainability (D4S), Design Methods, Product-Service Systems (PSS), Systematic Design, Quality Functional Deployment (QFD).

Introduction

Design for Sustainability (D4S) is an important and emerging trend for modern companies, and aims at developing products and systems able to minimize the impact about environmental, economic and human-related issues [1]. It is "important" since only a sustainability approach can preserve the available resources and permit future developments also for the next generations; it is "emerging" since companies are becoming more aware about the impacts of their processes on planet, profit, and people [2]. Moreover, such trend is pushed also by the spread of Information and Communication Technologies (ICT) in modern products, which are capable to share information, interact with other connected devices and store data in order to satisfy the user needs, offering the possibility to develop product-related services. The so-called Product-Service Systems (PSSs) represent the combination of physical products and tangible services, and can be applied also to increase both consumer satisfaction and sustainability [3]. However, PSS design is still difficult for companies, especially for the product-oriented ones: usually products and services are developed in a separated

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way and integrated only at the end, with low technical performances (mainly due to interfacing problems, low user acceptance, and data collection and storage), high costs (due to infrastructure issues and difficulties in business model definition) and low sustainability (due to not optimized assets and not necessary functionalities). In this context, the research considers a recently defined QFD-based methodology to support PSS design [4], and tests its application to a case study in sustainable building sector, focused on the definition of a new PSS for green roofs. Such a method starts from the analysis of the market needs and adopts a set of correlation matrices to find out the PSS functionalities, assets to be included, and partners to be involved in a systematic way. As a result, cost and resources are optimized in respect with the specific needs to be satisfied. Such a method is also compared with the traditional design methodology, based on focus groups and brainstorming, applied for the same case study. Results demonstrate how a rigorous design methodology can promote D4S and business modeling better than traditional methods.

1. Related works

Different classifications of PSSs have been provided in literature, but the Tukker's model is probably the most widely accepted [3]. It presents a PSS as an offer in a "product-service continuum", where three main models of PSS can be recognized: A) *product-oriented*, where the physical product is sold in a combination with services such as maintenance, recycling and customer trainings, which guarantee the functionality and a long use cycle; B) *use-oriented*, where the product is not owned by the customer anymore, but is made available for customer usage by the producer (e.g. through leasing); and C) *result-oriented*, where a "solution" required by the customers is provided in place of a product (e.g. offering travels instead of cars). In this context, firms can move from one type of PSS offering to another by changing the relative share of product and service components according to user requirements. Moving from the traditional products to one kind of PSS is called Servitization [5].

As far as PSS design is concerned, the literature review highlights that many methods and evaluation tools for PSSs have been proposed in recent years, and also the role of PSS in improving sustainability issues has been pointed out. However, there is still a lack of concrete and validated guidelines for PSS design in industry and its direct correlation to sustainability purposes. In this context, Ota [6] proposed a method for requirement analysis considering environmental factors, Favi et al. [7] offered a PSS lifecycle approach, Kimita and Shimomura [8] proposed a review of such approaches from different viewpoints (from value to cost, functions, qualities, or performances), and Peruzzini and Germani [9] used a structured approach to design sustainable PSSs. Recently, a combined methodology to support PSS design has been proposed to overcome the main limitations emerged from the literature review and achieve a successful PSS design process, focused on the satisfaction of the customer needs [4]. It is based on a set of correlation matrices to map the relationships between input and output data that are faced at each stage according to the Quality Functional Deployment (QFD) technique. It allows to progressively defined the customers' needs, the system requirements, and functions to be realized, until the partners' selection. Thanks to its systematic approach, such a method can promote also D4S, due to the control of resources involved step-by-step.

2. Case study

2.1. Motivation and PSS focus

The case study focuses on the ideation of a new PSS for the so-called "green roofs". Green roofs are typical elements for sustainable buildings and innovative urban architecture, that serve several purposes such as absorbing rainwater, providing insulation, creating a habitat for wildlife, providing a more aesthetically pleasing landscape, and helping to lower urban air temperatures and mitigate the heat island effect [10]. Green roofs are mainly adopted to optimize the roof surface, by creating new space with several usages, avoiding high costs to buy new land and improving the economic value of the property; to improve the microclimate, by the evaporation process on the roofs makes air more damp and cool in the surrounding areas; to decrease the water leakage, by evaporating more than half of the annual rainfall; to reduce the pollution by increasing the green surfaces, reducing sound reflection, and insulating by heat both in summer and in winter. Due to the numerous advantages, the market for green roofs is growing fast.

The company involved in the case study is a global firm that produces and sells green roofs since 1989. Its current offer consists of a set of modules (for any specific kind of plants or vegetation), including also installation costs, and a tailored irrigation system, according to the specific building project. The business model is a traditional B2C and the product ownership is totally transferred from the company to the customer. After product selling, additional services are usually offered to the customers, such as roof maintenance, which is fundamental to achieve the expected benefits and guarantee the roof long life. In the current offer, the product lifecycle is made up of four main phases: 1) Production, when the green roof modules and the irrigation system are built and prepared to be sold; 2) Use, that starts after the green roof installation and involves the exploitation and usage of the green roof for many years (according to the building lifecycle); 3) Maintenance, as an after sale service by the producing company, which provides all actions required to guarantee the roof wellbeing (e.g. change of a defective module due to died or dried vegetable), replacement or modification of the irrigation system, etc.); and 4) Disposal, that is required after the roof end-of-life, where all the plants are disposed of different manners, usually never reused. Actually, the producing company doesn't care about this phase.

The current offer presents several strengths and weakness. The strengths are: the modular architecture, the easy built and replace, the quick and easy installation, and the low risks for the company during the lifecycle use phase. About weakness, there are some main issues limiting the spread of green roofs usage:

- high costs for buying and installing for the customer,
- low level of customer relationship,
- lack of information about product use and disposal,
- high cost and effort for maintaining the roof in optimal conditions to have the expected benefits.

In order to overcome the current weaknesses, the producing company was interested in creating a PSS value proposition. Indeed, the company would offer a new value proposition to its customers in order to sell the green roof as a PSS, in order to expand its market. A new PSS value proposition will have to:

- reduce the purchase costs for customers, by spreading the system costs along the entire PSS lifecycle,
- guarantee installation and maintenance services in a unique offer, to simplify both installation and maintenance for the customers,
- improve the roof sustainable performances, thanks to a more accurate use and maintenance of the roof itself.

Unlike the traditional product offer, maintenance should be provided in a new way in order to monitor the roof behavior through a set of sensors able to collect information about irrigation storage system and from the surrounding ecosystem. This monitoring allows a continuous data collection and analysis, which enable automatic problem detection and preventive reaction, to avoid or at least limit dehydration and death of the roof plants. Furthermore, the new PSS solution could create a close loop lifecycle, where the defective modules (e.g. dried plants) can be suddenly replaced and regenerated to be used again (as a recycling service) in order to realize a more sustainable solution in terms of environmental benefits, economical expenses and human efforts necessary to care and handle with it.

Figure 1 compares the business models for the current product offer (A), and the PSS value proposition (B). The latter (PSS) aims to realize a more sustainable solution in terms of environmental impact, human efforts and economic impacts for the final customers; moreover, the producing company becomes the owner of the system, and the customers can have a improved and steady maintenance service along the entire PSS lifecycle, with a positive effect on the global green roof performance.

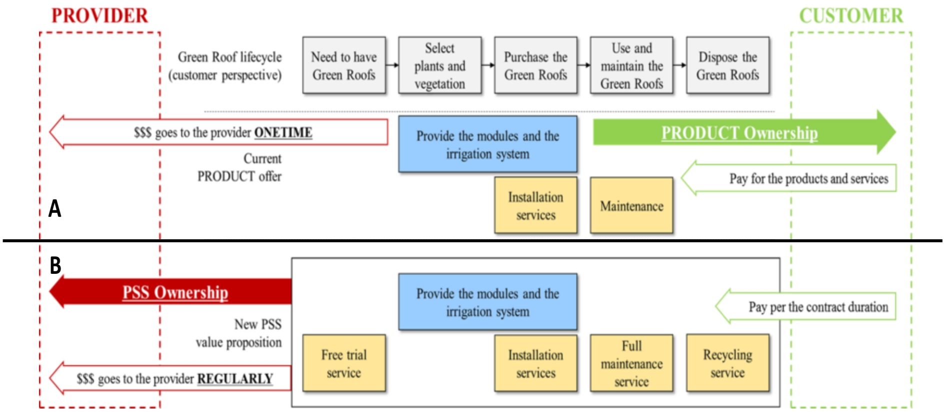

Figure 1. Business model comparison between the current product (A) and the new PSS proposition (B).

3. PSS design: traditional vs QFD-based method

The case study focuses on the definition of a new PSS for green roofs to overcome the main limitations of the current product solution. Two design processes are compared: a traditional process, driven by traditional design method adopted to PSS, based on brainstorming and focus groups, and an structured process, based on a recently defined QFD methodology, which starts from the analysis of the target market and user needs, and goes through the definition of requirements, PSS functions, ecosystem and business model in a systematic way [4]. The PSS design process was carried out by two groups of students, graduating in mechanical engineering and engineering management courses. One group adopted traditional approaches and the other one the QFD-based method, after a brief presentation of them to the students. The two design teams worked in parallel and were supported by people belonging to the producing company of the green roof, especially from the Marketing, Technical and Service Departments.

3.1. Traditional PSS design

The former group developed the new PSS idea by traditional design approaches, according to the following steps:

- Study of market analysis, carried out by the marketing company staff;
- Focus groups and brainstorming sessions, in order to investigate the main limitations of the current product and identify the context in which the new PSS will be introduced;
- Analysis of the new PSS characteristics and investigation of the scenarios where PSS will be used;
- Simulation of how the new PSS will be created provided and maintained, mainly by Business Use Case (BUC) analysis [11].

During the focus groups, the main strengths and weaknesses of the current product offer were assessed in order to identify the new PSS value proposition. By one-day brainstorming, students identified the most promising ideas about the functionalities of the new PSS solution. Subsequently, the main PSS characteristics were identified in order to understand whether and how the new PSS could validly substitute the current product offer. The results from the design activity brought to the definition of the main PSS features. Finally, the new PSS idea was simulated adopting the BUC approach to define its impact on the customer' satisfaction and the hypothetical PSS use scenario.

3.2. QFD-based PSS design

The design of the new PSS, as presented in section 2.1, was faced through the application of a QFD-based methodology as proposed by Marilungo and Peruzzini [4]. Such a methodology integrates several techniques, and basically focuses on the analysis of the market needs and their correlation to the technical requirements, through the application of a set of QFD matrices. The main design steps were:

- Identification of the customer requirements and main PSS functions on the basis of the market analysis, carried out by the marketing company staff;
- Correlation between customer requirements and PSS tasks by ethnography and participatory design techniques (based on personas) [4], according to the specific PSS focus and customers' objectives. Requirements are defined according to [12];
- Technical analysis where the PSS assets required are identified through the analysis of the main tasks to execute, and correlation between assets and PSS functionalities according to the PSS application scenarios, to define the most affected assets, which then are correlated with the partners' resources needed to involve;
- Simulation of how the new PSS will be created provided and maintained, mainly by BUC analysis [11].

Table 1 shows the correlation between the identified user requirements and the technical tasks. User requirements were collected by the design team in the basis of a preliminary market analysis, thanks to the application of requirements elicitation techniques, while PSS tasks were defined coherently to the PSS value proposition. Table 2 shows the correlation between assets and functionalities. The assets are the tangible or intangible recourses needed to realize the tasks; the functionalities are what can be delivered to satisfy customers. For the specific use case, Table 2 shows the assets and their correlation to the tasks presented in Table 1. As a result, the PSS functionalities were defined. They are:

1. *Green place*, which consists of simply offering an urban green area;
2. *Comfort place*, which offers to change house roofs in more sustainable and confortable spaces;
3. *Insulator house*, which provides a thermal and acoustic insulation of the building;
4. *Economic saving*, which can be achieved thanks to both the water storage system, allowing to avoid water waste, and the heating / cooling features that allow saving money for house heating or cooling;
5. *Ever green and maintenance*, which consists of regeneration of expired vegetation, provided as a service.

Finally, Table 3 shows the correlation between the PSS assets, as identified in Table 2, and the partners' resources required to provide such the assets. About resources, Table 3 shows only the main partners involved in the company supply chain (due to space limit). Correlations are expressed according to 0-1-3-9 scale.

Table 1. Correlation between PSS tasks and user requirements by QFD method.

GR = Green Roof	**USER REQUIREMENTS**											
TASK	Have an urban area at zero	Emphasis on environmental	Improve the live quality	Turn the city into an island green	Improve the thermal	Increase the buildings energy	Easy to installation and	Improve acoustic insulation	Make a green building	Reduce risks due to weather	Have vegetation always green	**TASK IMPORTANCE**
Furnish the GR	9	9	9	9	1	9	0	9	9	1	3	**68**
Make a modular space	0	1	9	0	0	0	9	0	1	1	0	**21**
Greening of the GR	9	9	9	9	3	9	0	0	9	9	9	**75**
Installation of GR waterproof layer	1	1	1	1	9	9	3	0	1	0	3	**29**
Maintenance actions on the GR	3	3	3	9	0	1	9	0	3	3	9	**43**
Feasibility analysis	3	0	0	0	1	0	0	0	1	0	0	**5**
Installation of drainage ditch	0	1	3	1	1	3	3	0	1	0	3	**16**
Realization of GR modules	3	1	3	1	9	9	3	9	9	9	3	**59**
Creation of water storage system	1	1	1	1	3	3	3	0	1	0	3	**17**
Creation of irrigation system	3	1	3	1	0	1	3	0	1	0	9	**22**
Design and creation of sensors system	0	3	0	0	0	0	0	0	1	9	9	**22**
REQUIREMENTS IMPORTANCE	**32**	**30**	**41**	**32**	**27**	**44**	**33**	**18**	**37**	**32**	**51**	

Table 2. Correlation between PSS assets and functionalities by QFD method.

	PSS FUNCTIONALITIES					
ASSETS	Green place	Comfort place	Insulator house	Economic saving	Ever green & maintenance	**ASSETS IMPORTANCE**
Modular structure	3	9	3	0	9	**24**
Plants and vegetation	9	3	9	9	9	**39**
Substratum and drainage material	3	1	9	3	3	**19**
Drainage ditches	3	1	3	9	3	**19**
Components for water storage	1	1	3	9	3	**17**
Other accessories	0	9	0	0	1	**10**
Filter layer	1	1	3	0	3	**8**
Waterproof coat	1	1	3	9	3	**17**
Irrigation system	9	1	1	3	9	**23**
Sensors system for monitoring	9	3	0	3	9	**24**
DB to data collecting	9	1	0	3	9	**22**
FUNCTIONALITIES IMPORTANCE	**48**	**31**	**34**	**48**	**61**	

Table 3. Correlation between PSS assets and partners' resources by QFD method.

	ASSETS											
PARTNERS' RESOURCES	Modular structure	Plants and vegetation	Substratum and drainage material	Drainage ditches	Components for water storage	Other accessories	Filter layer	Waterproof coat	Irrigation system	Sensors system for monitoring	System DB	**PARTNERS IMPORTANCE**
GR builders	9	0	0	3	3	3	3	3	3	1	1	**29**
Vegetation providers	3	9	1	0	0	0	0	0	1	1	0	**15**
Designers for GR furnishing	0	0	0	0	0	9	0	0	1	0	0	**10**
Gardeners	3	3	3	1	1	1	3	1	3	0	0	**19**
Substratum providers	3	3	9	0	0	0	0	0	0	0	0	**15**
Engineers and technicians	3	1	1	9	9	3	9	9	9	1	1	**55**
GR engineers	0	0	0	9	9	1	3	3	3	3	3	**34**
HW provider for sensors system	0	0	0	9	9	0	1	1	9	9	3	**41**
SW provider for sensors system	0	0	0	0	0	0	0	0	3	9	9	**21**
Data manager	0	0	0	0	0	0	0	0	9	9	9	**27**

3.3. Results and discussion

In order to compare the two PSS value propositions as designed by the two approaches (i.e. traditional and QFD-based), the main results coming from the two design teams are presented and discussed. The traditional approach allowed the current product offer to be analyzed in order to identify the more profitable PSS and to highlight the main drawbacks, mainly referred to service potential, product design, innovation, adaptability, client contact, and operational performance. Such an analysis highlighted the main points to improve by a proper PSS. Indeed, the design team defined a new PSS scenario, even if a low level of detail. Different ways to implement the maintenance service into the product offering and some solutions to have a more profitable customer relationship were proposed. However, it was long and difficult to achieve a complete PSS solution. The main outputs of the preliminary design phases were a set of diagrams as indicated in Figure 2 (arrows highlight the main areas of improvement identified during the focus group).

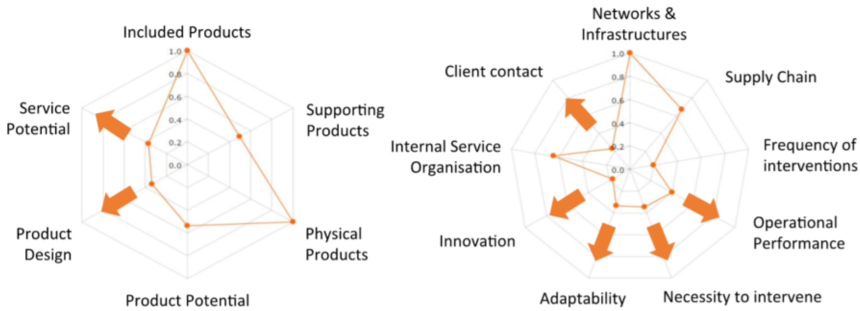

Figure 2. Outputs from traditional design approach: areas of improvements for the PSS development.

Instead, the QFD-based methodology supported not only the definition of the main PSS features, but also the identification of the PSS functions and assets (i.e. tangible and intangible assets, resources required to implement the service over the product, key partners to involve). Furthermore, it supported a preliminary business modeling for the new PSS by the application of the matrices. The preliminary business model is shown in Figure 3: such model proposed a low installation cost and an annual fee for maintenance actions, in order to give a reasonable return of the investment for the company provider and a good “value for money” for the customers.

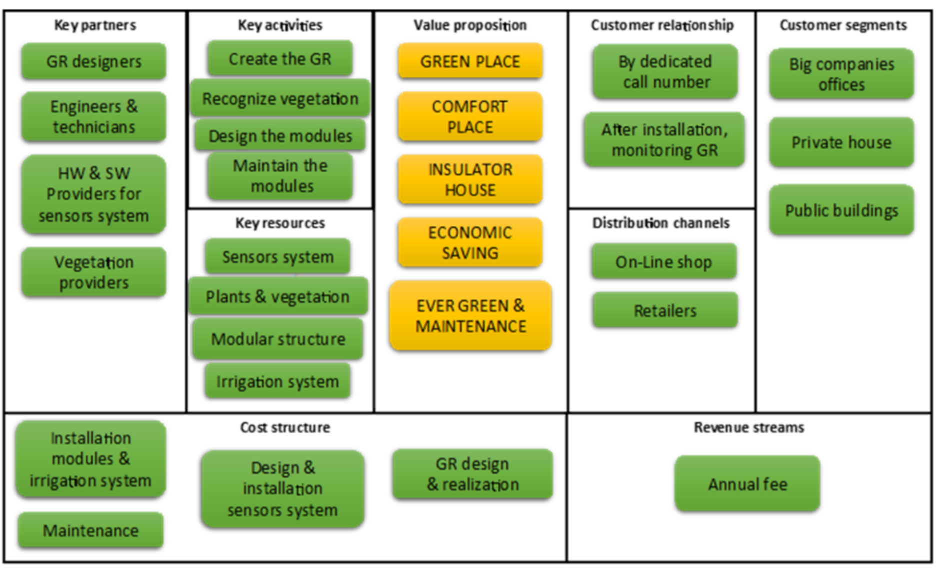

Figure 3. Outputs from the QFD-based design approach: preliminary PSS business model.

Furthermore, the adoption of a structured methodology for PSS design allowed the new PSS lifecycle to be detailed in advance and the impacts on sustainability analyzed during the design phase, to be compared with the traditional product lifecycle. As a result, the positive contribution of the new PSS solution with respect to traditional product lifecycle as presented in Figure 4. Indeed, the traditional model implies waste of material and product in the disposal phase, which brings to higher cost and resource leftover. Contrarily, the PSS solution allows recovering products and materials thanks to same ownership according to a close-loop model, saving resources and money. Such results demonstrated how the adoption of a structured methodology, as the QFD-based one, can simplify the design and the implementation of service-oriented PSS with better performances and higher sustainability (i.e. reduced costs, lower environmental impacts, less human intervention). Further developments can refer to the definition of a PSS workflow in a more structured way, as recently presented by Viriyasitavat [13].

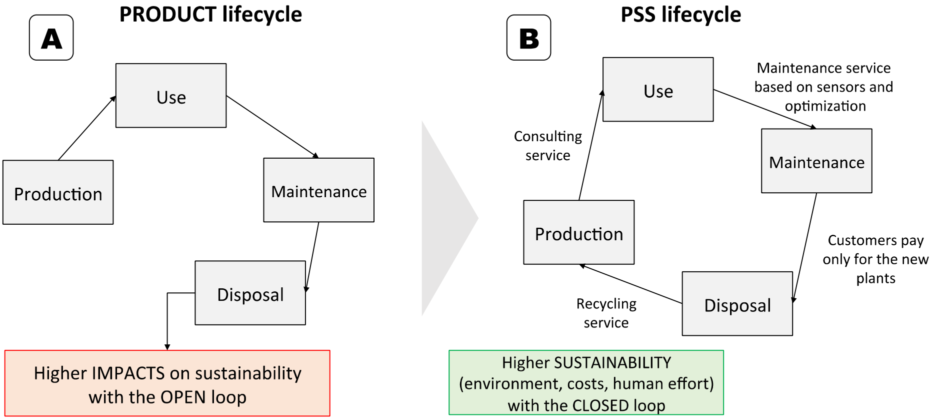

Figure 4. Impacts on sustainability due to traditional product lifecycle (A) and new PSS lifecycle (B).

4. Conclusions

The research proposed to apply a QFD-based methodology to design sustainable PSS in order to promote Design for Sustainability (D4S) also among PSS and presented a case study where non-expert designers will develop a PSS in the green roof sector, starting from the main limitations of the current product offer. Two groups were involved, supported by the producing company of green roofs: the first group adopted traditional approaches based on focus groups and brainstorming, while the second group adopted the proposed QFD method. The second design team was able to study consumer needs more deeply, to consider technical aspects more consciously, and to evaluate also business aspects. As a result, the level of servitization and the global PSS quality achieved by the second PSS was higher in respect with traditional methods. Such a result suggests how D4S can be achieved easily by means of structured methodologies, like the proposed one. Future works will be focused on testing the expected benefits in terms of reduced environmental, economical and human-related impacts also on real PSS prototypes by proper simulation tools.

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Bridging the Gap Between Functions and Physical Components Through a Structured Functional Mapping Chart

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Abstract. Functional modelling can be challenging to integrate with physical CAD-modelling, since the natures of these representations are quite different. This paper presents a methodology seeking to bridge these representations in a product platform context. The contribution of this work is a pragmatic way to improve the connections between Functional Requirements and CAD models. It does so by structuring functions, features and components and by linking these through tags in CAD-models. The methodology thereby associates the CAD models to the functional knowledge used when creating them. The result is the functional mapping chart, which is illustrated by an example from the automotive industry.

Keywords. Functional modelling, product platform, functional mapping chart, design knowledge, CAD- modelling

Introduction

Functional modelling is an approach to describe products and platforms. By offering a structured way to organise functional requirements and design solutions it presents a way to describe complex relations in products and platforms. A strength of functional information is that it holds the rationale behind a design which is a key concept for knowledge about products and systems [1]. Functional information can be considered the core of a product and is not substantially changed over product generations. This is opposed to the geometrical information that is embedded in a Computer Aided Design (CAD) model; the product is the result of a design process but cannot in itself explain the rationale for why it is designed in a certain way.

A barrier for the application functional knowledge is that it sometimes is formulated as a vague or abstract description of design solutions that cannot be immediately embodied into physical components. Literature such as [2, 3] describe functional modelling but lack support for how to move from a functional description to a concrete solution that can be used as a basis for engineering design. It describes *what* must be achieved, but not *how* to achieve this in detail. For geometry, these details are defined by the CAD-model. A combination of the functional model and its corresponding product description in CAD would therefore be beneficial for increasing

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the product knowledge within an organisation. Even the simplest product family can consist of hundreds of unique components including special variants and discontinued parts. It is impossible for a designer to recall how every shape of each individual component contributes to the functionality of the overall product, which is the motivation for developing this new methodology.

The research in this paper is a spin-off from an earlier project carried out at an automotive supplier. The research method is based on a literature synthesis to form the methodology. Data from the company is then used to illustrate it.

The purpose of the methodology is to improve the product development process by linking CAD models to the functional knowledge used to design them. The objective is to present a feasible approach to visualise and structure key information from the functional model and map this onto a CAD model, thereby providing the benefits of a functional approach in practical design work.

1. Literature review

The literature base on platform scoping is mainly focused on detailed design, associated with parametric CAD. This research instead focuses on a phase in-between functional modelling and detailed design. It contributes with a way to link functional requirements to concrete CAD- design, seeking to support this with a functional product platform approach. The focus of the paper is to develop support for concrete embodiments of physical components based on the Configurable Component framework. Therefore the literature review is limited to literature in the field.

1.1. Functional modelling

Functions are often confused with solutions. This work follows the view of Andreasen [4], where a motor is not considered a function but rather a design solution fulfilling the Functional Requirement *provide kinetic energy*. A hallmark of functional knowledge is its generality as opposed to knowledge sealed in a product feature, or “function carrier” [5], that cannot easily be extracted whilst it has been transformed into an physical component.

Products and platforms can be modelled according to the Function-Means (F-M) methodology [4, 6, 7]. This is a technique for functional decomposition and concept generation of systems and products. It presents a systematic way of arranging functions and solutions to functions in a hierarchic tree structure as depicted in Figure 1. It is an object-relational model that describes the Functional Requirements (FR) for the system and what Design Solutions (DS) that can be used to meet these requirements.

Creating the functional model is a creative work, zigzagging between FRs and DSs where a chosen technology will render specific sub-requirements.

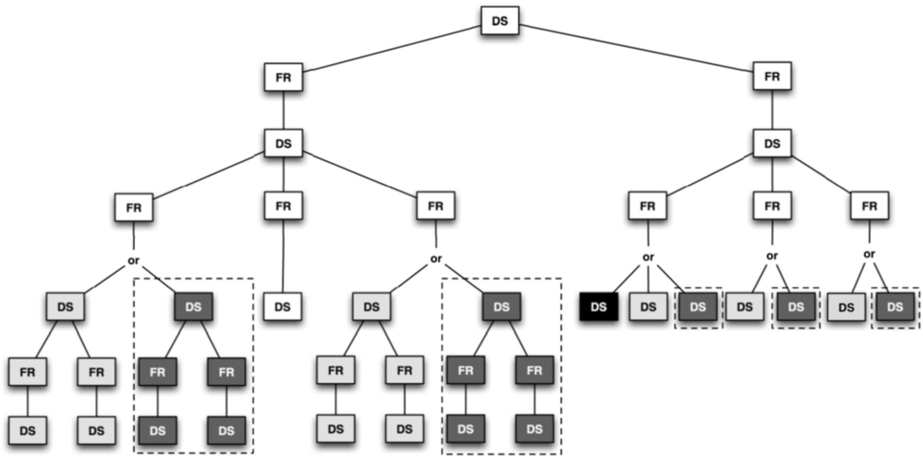

Figure 1. The white objects are present in all configurations and the shaded objects are present in some. The dashed branches represent alternative configurations. In order for the Functional Requirements to be fulfilled, all embodying Functional Features must be mapped to components. Redrawn after [8].

The tree ends at the detailed level [9] as Functional Features (FF), which is the name of the last DSs before embodiment. Note that for the FRs to be fulfilled, all FFs must be mapped to components and used.

1.2. Mapping functions and physical components

An extension of F-M modelling to support the development of product platforms is the Configurable Component (CC) framework [10] that presents an object oriented approach of modelling platforms. In this context Levandowski, et al. [11] introduce the concept of components to describe how functions can be allocated to the physical artefacts that realise the desired functionality. The authors introduce a model of components in the product and manufacturing system and outline a process for its use.

A result of the mapping is seen in Figure 2. Here, several types of mappings of functions to physical components are displayed. When several FFs are mapped to a component, function sharing occur, which is characteristic of integrated architectures [12]. An example is given in Figure 2 at the dashed arrows marked with B. Here two FFs are allocated to the component, the Airfoil-shaped vane. The component uses strut segments that convey mechanical loads and the geometry of the outer surfaces turn the swirling flow of the Low Pressure Turbine. Figure 2 also shows how the circumferential flanges FF is realised by three physical components.

The CC framework is supported by the Configurable Component Modeller (CCM) that can model the objects and relations in the CC´s [13]. It is used in the design phase to instantiate different product family members from a platform model and exports these as design parameters to CAE software. However, the software is not supporting detailed design work in the process of embodying detailed FFs into physical components.

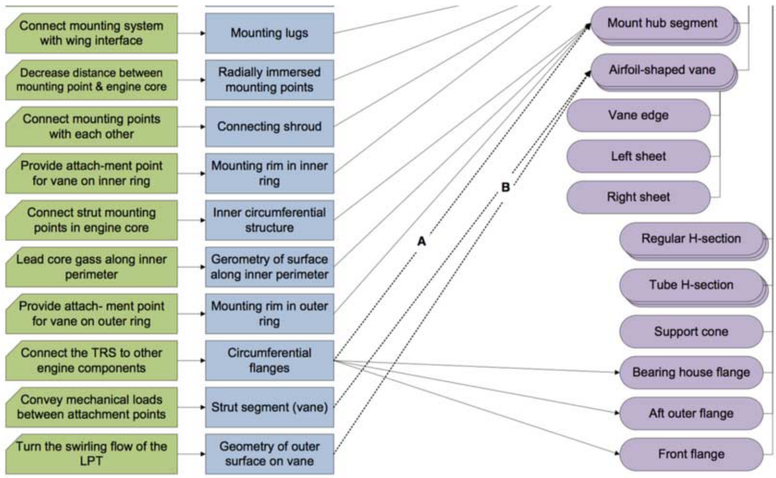

Figure 2. Extract of the mapping of Functional Features in an aerospace component. A physical component can carry several Functional Features as seen in A, as well as dividing a Functional Feature between physical components as shown in the bottom of the figure. After [11].

2. A methodology to support the design of physical components through functional modelling

This work presents a methodology that helps designers take advantage of the information residing both in a functional product / platform description and in product description data i.e. CAD. The methodology can be used with most CAD systems and be supported by platform modelling software such as CCM. It can also be used manually if no previous functional information exists by using traditional F-M methodology.

One reason for the difficulties encountered in the transition between functional representations and concrete solutions is the significant gap between a defined functional requirement and a physical component. This gap is bridged by the engineering design process and there is no simple solution to bypass it since it requires skill, experience, and creative design work. The ambition of the methodology is therefore not to fully bridge this gap, but rather to visualise and link the relations between functional models and CAD models.

Re-design can be caused by different reasons. If new functionality is needed due to changing customer preferences then the new FR will be needed which create a new branch in the F-M tree. If a new way to solve current functions is requested then a new DS is introduced, that, in turn may also create a new branch. From a functional view, the end result is the same, a new FF that must be embodied in a component. To fulfil an FR, all FFs that lie underneath it must be allocated to components.

2.1. Creating the functional mapping chart

The core of the methodology is the *functional mapping chart*. The suggested process to create the functional mapping chart goes through the steps of Table 1:

Table 1. The steps used to create the functional mapping chart.

Step	Description
1	A Function-Means tree is constructed representing the relevant parts.
2	The functional model is broken down to the concrete level in the Function-Means tree. This is the sufficient level at which the functional model can be transformed into a physical component.
3	The Functional Features at the concrete level are embodied into physical components.
4	A functional mapping chart is created. It visualises the Functional Features, the governing Functional Requirements and the name of the physical component or components that the Functional Features are integrated into.
5	All Functional Features must be used in the embodiment; otherwise the corresponding Functional Requirements are not fulfilled. This can be verified by using the functional mapping chart.
6	The Functional Requirements are used to tag features in the associated CAD model to pinpoint where functionality is created by the Functional Features. This enables traceability between the functional model and the physical components.

A F-M tree is constructed and one way is to follow the process given by Levandowski et.al. in [9]. The functional model is broken down to a sufficient level, at which the functional model can be transformed into a corresponding physical component. To fulfil a functional requirement, there must be a FF allocated to it. These are found at the concrete level in the F-M tree [9] representing the most broken down level. Functionality is handled by the FFs that are embodied into physical components, sometimes called function carriers [12].

Several FFs can be integrated in a component. This creates a potentially massive design space since each FF may be designed in several ways and also be distributed differently over components. Two different mappings of FFs to a sheet metal component are seen in Figure 3.

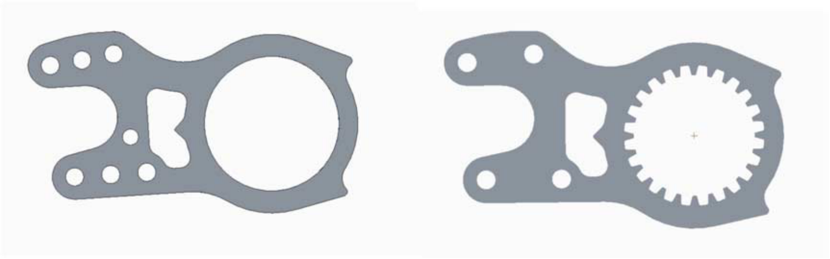

Figure 3. The FFs can be embodied in different alternative components, enabling a Set-based approach. The fulfilment of the governing FRs can be assessed through the functional mapping chart. As an illustration, the right variant also fulfils the FR "adjust back rest angle" through its internal gears.

The massive design space is suitable for a Set-based approach thereby creating sets of alternative architectures. A way to evaluate different architectures is presented in [14] and can be used to compliment the method described in this paper.

After going through the steps of the method the functional mapping chart can be created. It is based on a template that visualises the FFs, its governing FRs and the identification of the component that carry the FFs. Most of the information can be generated from the platform through the software CCM and exported to Excel. It can also be created manually by identifying what FFs that are satisfying which FRs and what components they are integrated in. The functional mapping chart is used to visualise and structure how FFs are distributed over components and to identify if some FFs are not allocated; all FFs must be used in the embodiment otherwise the corresponding FRs are not fulfilled. The functional mapping chart can also be used in a morphological approach as a creative tool in the embodiment process to distribute FFs over components in different ways.

3. Applying the methodology to an example within automotive design

The approach is illustrated by an example of mechanical design based on data from a previous study at an automotive sub-supplier. It illustrates a case of re-design of the sheet metal bracket in Figure 3 that is reused in different models of automobile driver seats in a part-based product platform. It is a part of the mechanism that adjusts the backrest angle. The seat consists of several hundreds of unique components. It is also part of a larger platform of seats so it is impossible for a designer to know all the features of each individual component. A part of the F-M tree is seen in Figure 4:

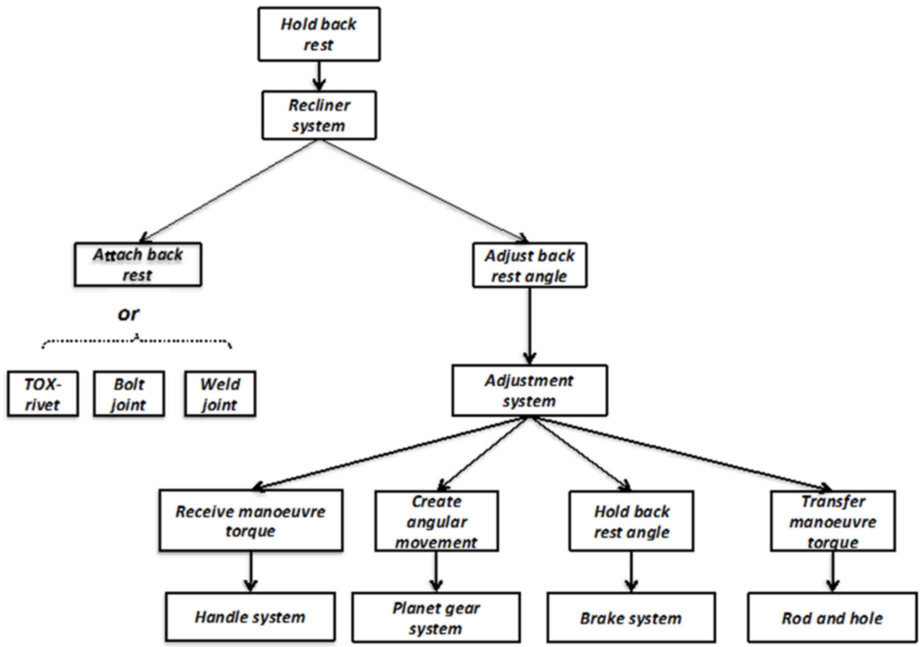

Figure 4. A functional breakdown of the Functional Requirement *hold backrest.*

In the presented case, the firm needs to reduce the weight of one product due to changing customer requirements. To fulfil the new requirements the designers decides to change the material in the seat frame from steel to aluminium so a steel component can no longer be welded to the frame and another joining method is needed. The sheet metal bracket is found in a plurality of different steel seats and therefore cannot be redesigned in aluminium so the firm decides to create a new bolt joint bracket. There are several fastening concepts used in the firm and the most common joining method is welding. In some applications the components are also riveted together or joined by bolts. The FFs that are used in the example are extracted from the functional model in CCM and adapted to the functional mapping chart as can be seen in **Figure 5**.

Functional Requirements	Functional Features	TOX-rivet	Bolt-joint	Weld-joint	Handle-system	Planet-gear-system	Brake-system	Rod-and-hole
Attach-back-rest		●	●	●				
Recieve-manoeuvre-torque					●			
Create-angular-movement						●		
Hold-back-rest-angle							●	
Transfer-manoeuvre-torque								●

Component Id	Functional Features	TOX-rivet	Bolt-joint	Weld-joint	Handle-system	Planet-gear-system	Brake-system	Rod-and-hole
Current-welded-bracket				●		●		●
Current-riveted-bracket		●				●		●
New-bolt-joint-bracket			●			●		●
Knob					●			
Friktion-plate							●	

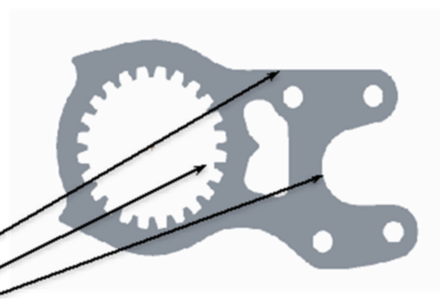

Figure 5. The functional mapping chart and its mapping of Functional Features to the bolt joint bracket. The Functional requirement governing these FFs can be tagged to the CAD model thus enabling traceability between the F-M model and the component.

A general guideline for finding the right level of functional breakdown cannot be formulated. This level is connected to the system borders and interactions with other components. The general methodology however, is to start with larger units and break down these further as needed. As an example the handle system in Figure 4 has several sub Functional Requirements. It must fit the users hand, enable an interface to the mechanism, withstand the manoeuvre forces and be securely positioned so that it does not fall off. All this functionality can be integrated into a single function carrier such as a plastic knob that in turn can be supported by its own functional mapping chart. The knob is not functionally connected to the bolt joint bracket and is not further elaborated in this example.

Following the identification and creation of FFs trough the functional breakdown, the FFs are transferred to the Excel template in Figure 5 where the FRs and their mapping to FFs and components also are visualised. A complete model according to the CC framework have additional interactions that can be used to suggest which FFs should be integrated into the same component but for brevity these interactions are not discussed here.

The FR attach backrest can be fulfilled by the three types of manufacturing methods. A strength of the methodology is that redundant FFs that solve the same FR can be visualised and enabled in the CAD-geometry of a component. This is shown in

Figure 6 as markings for all three joining FFs for the new bolt joint bracket. If one feature imposes limitations on the design, the functional mapping chart shows the consequences for other parts of the design if the feature is removed. It is therefore an active decision to delete a feature from the CAD-model rather than an unaware change in geometry. This is also an application of a Set-based way of working [15] building on the principle ensure feasibility before commitment which has proven to be an effective way to work [16].

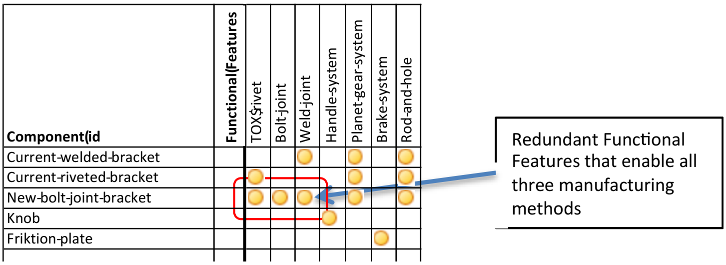

Figure 6. Redundant Functional Features are integrated in the new component in order to allow its use in different applications.

After deciding which FFs that should be integrated in the new component the CAD model can be created. Each FF is tagged with the identification of its governing FR thereby identifying the FFs in the functional model and its design rationale. Figure 7 shows the tags in the CAD tree.

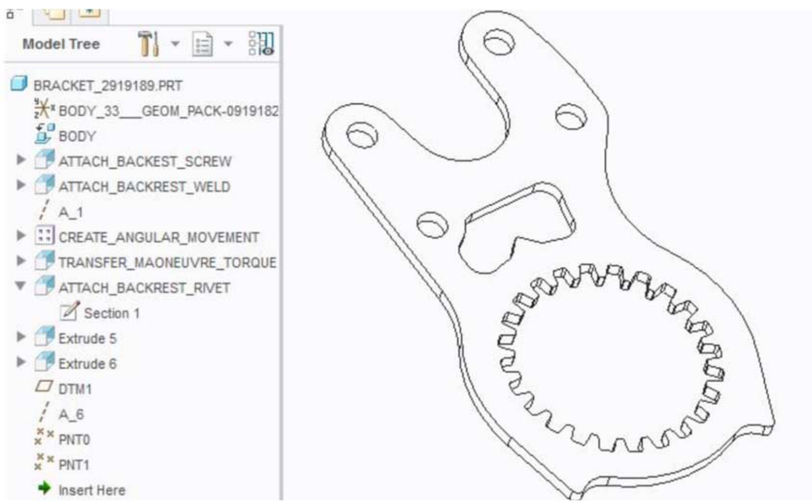

Figure 7. The Functional Features are tagged and visualised by renaming features in the feature tree of the CAD- system. This functionality exists in all major CAD-software, also in "featureless" systems. Note that there are three redundant FFs that solve the same FR, ATTACH_BACKREST. This is because the component is assembled differently in different variants.

Renaming the features is a manual process with a limited effort since each CAD model only has a few FFs to rename. It took less than 5 minutes to tag the whole model in the CREO software used in the example, which should be considered a small effort compared to the gains in traceability in the case of a redesign. To further structure the functional information, this could be collected according to the A3- methodology given in [17] to form a knowledge repository.

4. Conclusions

The presented methodology offers a new way to visualise, structure and link information between a functional model and a traditional CAD model. It does so by using a structured functional mapping chart to bridge these two types of knowledge representations.

The functional mapping chart clarifies why a component is designed in a specific way and links the CAD-model to the functional model. The chart identifies the CAD-features that are used to embody and fulfil the Functional Requirements. The methodology thereby supports the product development process by bridging the gap between the functional knowledge used to design a product and its related physical CAD representation.

The methodology can be applied to re-design, in structured innovation and for sustaining design knowledge:

- In order to efficiently re-design a new product, a deep understanding of the previous design is essential. Such understanding can be supported by the methodology in providing functional information that clarifies the reasons behind the design at different levels of abstraction.
- For structured innovation the methodology supports a morphological approach to visualise and to distribute functionality over physical components. The design space can therefore be systematically explored without the risk of overlooking any of the needed Functional Requirements.
- In a re-design context, product knowledge may be lost over product generations and through turnover of personnel. The methodology presents a way to improve this situation by enabling traceability between CAD models and the knowledge used to design them.

The contribution of this work is a pragmatic way to bride the gap between functional descriptions and physical components. The modelling software used in the example is beneficial but not necessary for using the methodology. It can be applied in a general case based on standard F-M methodology and the functional mapping chart. Moreover, the methodology can be used with any CAD-system that allows users to rename features i.e. a majority of existing programs, including “featureless” systems. A minor change in CAD-methodology may be needed to ensure that the Functional Features are properly clustered and can be directly identified in the CAD-tree.

The research is a work in progress and evaluation of the methodology by professional engineers in an industrial setting is left for future work. Also the applicability of the methodology in cases other than mechanical design is not explored. There are however, no fundamental hinders for the methodology to be applied to other areas since the modelling of Functions and Means and the establishment of corresponding functional mapping charts have a wide applicability.

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Modularization in Concept Development Using Functional Modeling

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Abstract. This paper presents a set-based approach to use functional models for platform concept development to identify feasible modules at early design stages. The concepts are defined using functional requirements, design solutions and their interconnections. These models are then encapsulated into functional modules through clustering of Design Structure Matrixes (DSM). A metric is introduced to quantify the ability to modularize a certain concept, which may be used to assess and eliminate inferior concepts. The approach is illustrated using a case study from the aerospace industry. The result shows that modules can be identified by clustering of the functional structure. This has an integral effect on early division of work, possibility to design reuse, etc. The ability to modularize a specific concept The case study also shows that, despite of the traditionally integrated character of the product studied, it is possible to identify functional modules for reuse in a platform.

Keywords. Product platforms, functional modeling, modularization, design structure matrix, set-based concurrent engineering

Introduction

Modern products are significantly more complex than their predecessors. As this complexity is introduced, the developing companies are challenged to manage it in their design processes and organization. This is often solved by dividing the product architecture into manageable chunks, or modules, and dedicate specialized competence to each module. These modules can be developed in concurrency, as long as the interfaces between them are maintained. In product platforms, modules are used and reused as exchangeable design blocks to satisfy a range of customer needs, while simultaneously reaping the benefits of scale in production [1] [2].

However, current practice in modular platforms is based on the physical architecture of the product. This means that modularization as a means of supporting development is infeasible for companies with physically highly integrated products. Also, dividing a product into modules based on physical interfaces fails to provide support for early phases of concept development when the physical form is unknown, and where several conceptual solutions for the platform are developed, analyzed and evaluated.

Research has proven Functional Modeling a feasible method for concept development as a way to model conceptual solutions without requiring physical models

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[3]. The functional models enable integration of technologies from multiple domains, as parallel or complementary solutions. Though there is theory describing the need for, and the concept of, early modularization, no stringent approach is available [4].

This paper presents an approach to use functional models for platform concept development to identify feasible modules at early design stages. It applies an approach with several alternative design concepts, which are assessed in their ability to be modularized. The platform concepts are defined using functional requirements, design solutions and their interconnections. These models are then encapsulated into functional modules to reap some of the benefits from modularization, already at early concept phases.

1. Background and Scope

1.1. Modularization and Design modeling

The encapsulation into modules allows engineers to study the systems and their interfaces on a high level without considering every detail [5]. There are accounts of several different facets of modularization. For example, Mattson and Magleby [7] divide modularity into design, manufacturing and customer modularity. The definition of design in this case aims towards detailed design, rather than concept development.

When applying modularization in the design phase, it allows for concurrent engineering by dividing the effort and knowledge need into manageable tasks. In conjunction, it provides a structure to coordinate tasks and decisions [9]. According to Simpson [10], modular platforms enable horizontal leveraging, i.e. to serve a range of customer segments by providing different functionality. Knowing early what capability and and bandwidth a platform concept has may be useful in selection of concept.

The objectives for modularization determine what constitutes a good module [8]. Also, Shoval [11] concludes that “systems may require different modularization architectures in different lifecycle phases”. Consequently, if a company aims to support design decisions in early phases, the modular structure should be based on functional models, rather than physical embodiment.

1.2. Set-based concurrent engineering

Sobek, et al. [12] summarize SBCE as engineers and product designers “reasoning, developing and communicating about sets of solutions in parallel and relatively independently.” They further define three principles that apply to a set-based design process: *map the design space, integrate by intersection and establish feasibility.* Through these principles, SBCE addresses issues with regular product development by considering a broad range of alternative design solutions that are systematically narrowed down by eliminating undesirable solutions [13]. An integral part in SBCE is to create tangible information on which to base design decisions [14].

As modularization is an integral part in facilitating concurrency in design, it is also an enabler for set-based concurrent engineering. In addition, the ability to modularize a concept may very well be reason for keeping in, or eliminating it from, the set.

Though often associated with detailed design, SBCE is applicable for concept development. Raudberget, et al. [15] illustrate how interconnectivity in a functional model can be used as a means for eliminating inferior design concepts in early design stages.

1.3. Design modeling in concept development

The prevailing paradigm in many engineering companies is a design support structure constituted of tightly connected CAD and CAE systems. While this provides excellent capabilities for analysis and synthesis based on geometric representations of the design, it fails to support phases where ideas and concepts are explored without physical embodiment [17]. In these early phases of ideation and technology consideration, formal support is rare in practice.

Functional models, if used right, support concept development with their inherent capability to express structures without explicit physical attachment. The EF-M model, developed by Schachinger and Johannesson [18], provides a structure of functional requirements (FR) that express system needs and design solutions (DS) for these. There are several relationships between the objects in the EF-M tree. The *interacts_with* (iw) relationship between DS is of great importance since it expresses functional interaction. The iw are asymmetric.

1.4. Design Structure Matrixes in engineering design

A DSM is can be used to represent elements and their connections in a standardized way. In a DSM relations between different elements are represented in a matrix, showing all elements in rows as well as columns. Interactions are marked at in the cells, with the direction row to column.

To cluster a DSM, the elements are rearranged so that the number of connections in between the different clusters is reduced to a minimum. As a direct consequence of this, relations of elements are accumulated inside the modules. As a conclusion of this, an appropriate clustering algorithm optimizes for maximum internal connectivity together with minimal external connectivity.

Hölttä-Otto [4] suggests a clustering algorithm for finding modules in functional and physical structures. The algorithm is based on the Idicula-Gutierrez-Thebeau Algorithm (IGTA) for clustering Component-DSM which assigns elements to new clusters, evaluates the new positioning and chooses the best possible allocation. IGTA is explained in detail in [19].

1.5. Scope and research method

In the phase, the design work is not yet constrained by assumptions of the detailed design or a physical form but allows for free ideation. These ideas are formally modeled as functional architectures. On that note, this paper aims to elaborate on two questions: (1) *How can modularization be supported in the concept development phase?* and (2) *How can* ability to modularize *be used as a criterion to compare different design alternatives?*

The research in this paper was carried out as a part of the VITUM research project. The project aims to develop virtual demonstrators for aircraft engine component design. The partner company is GKN Aerospace Engine Systems Sweden, which designs and manufactures engine parts for the aerospace industry. The project grants the researchers access to real design data, for verification and development of methods. The illustrating use case in Chapter 3 was developed together with GKN Aerospace. The models were developed by the researchers and validated through project meetings and workshops.

2. Modularization in Concept Development Using Functional Modeling

This section accounts for the approach suggested to define and use modules in concept development. The approach specifically addresses development and assessment of trans-disciplinary design decisions. Defining modules in early phases enables modularity for designs that are traditionally not modularized (i.e. physically integrated designs).

A key objective is to identify what knowledge is needed to realize different parts of the design. To facilitate concurrency, a second objective is to minimize the number of interfaces between design teams that need to be maintained, and clarify the character of those interfaces. How well an Architectural Option (AO) performs in terms of modularity is used as a criterion for pursuing or eliminating that design.

The approach builds on SBCE as a framework for expanding the design space, assessing it, and narrowing it down using modularity as an assessment criterion. The AO are modelled as EF-M. Figure 1 illustrates the suggested process for *modularization in concept development using functional modeling*.

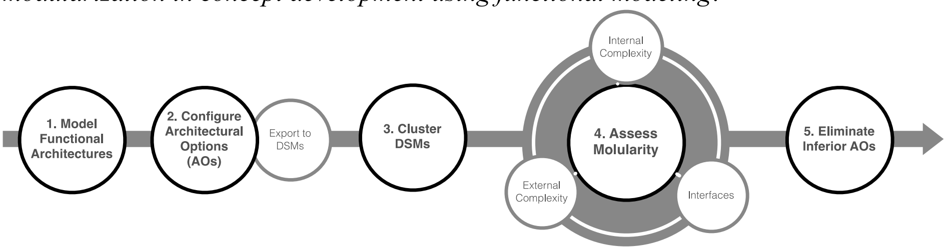

Figure 1. The suggested work process for modularization in concept development using functional modeling.

2.1. Modelling Architectural Options

As a first step, the product is modelled using EF-M trees. For novel designs, the EF-M is created from scratch, or in case of incremental design it is expanded. To *expand the design space*, several alternative DSs may be considered for each FR. The variety may be introduced on any level in the EF-M tree, which when done will have several alternative branches and leafs. The *interacts_with* relationships are modelled between DSs and express the functional connections across branches in the tree. The *iw*s are modelled on a conceptual level, as the information about the designs in early phases is limited. By combinatory operations, the DSs are compiled into a discrete set of architectural options, including the iw-relationships. These are transformed into a DSM with DSs as rows and columns, and iws marked in the cells of the matrix. Each AO is represented by one DSM.

2.2. Modularizing functional models

The DSM created from the functional structure is clustered using an IGTA implementation in CAM. Modules that share very complex interfaces can be accumulated into super-modules. The clusters can be collapsed to show only the assembly structure, as shown in Figure 3. From the initial clustering, shown in blue boxes, a new cluster, highlighted in green, is formed due to the high connectivity between the two modules.

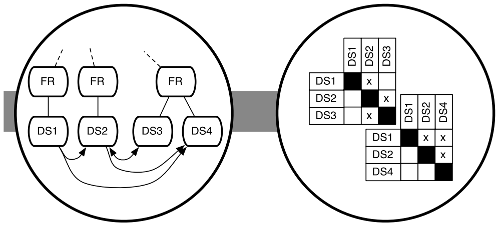

Figure 2. Step 1 and Step 2 in the process. The EF-M model represents two possible architectural options which are converted to two separate DSMs.

Shown with orange boxes are the interfaces between the different modules. In the collapsed state, the interfaces are kept and reduced to a single interaction between the submodule and the element, as seen with the connections DS6-DS1 and DS6-DS2 which are then collapsed to DS6-Cluster 1A.

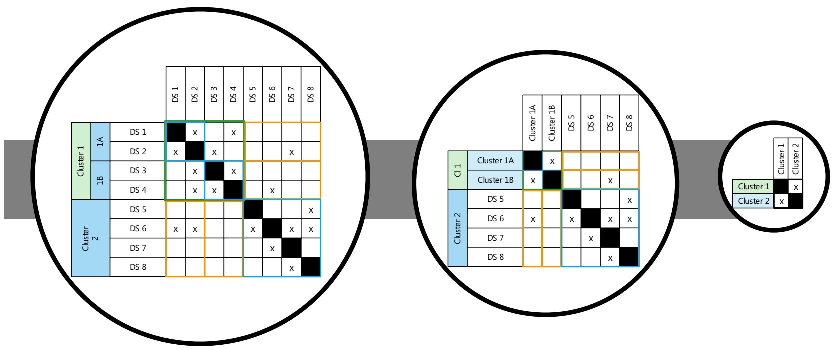

Figure 3. Example of multi-level clustering and collapsing of a clustered DSM.

Once the DSM is clustered into modules, the functional structure can be evaluated for its quality in terms of modularity. This assumes that the clustering algorithm applied has found the best way to cluster each functional structure. The metrics are internal connectivity, external connectivity and interface complexity.

Internal connectivity is measured through how many of the possible connections in a cluster are active, which is calculated by $c_{int} = \frac{x_{iw}}{n^2-n}$, where x_{iw} is the total number of internal connections and n the number of elements in the cluster. The value for c_{int} reaches from 0 to 1, with 1 as the most desirable value representing the highest possible internal connectivity.

External connectivity is measured by two factors, the average number of interfaces per module and the average number of connections per module. For each module only the interfaces to highest level modules were counted, and for high-level interfaces the connections of the internal modules were counted in collapsed state.

Interface complexity is evaluated by the average number of connections per interface, however detailed analysis of the distribution among the interfaces has to be observed. For modules sharing complex interfaces a regrouping into a super module might be beneficial.

2.3. Eliminating inferior design alternatives

Since external connectivity is expressed by two factors, optimizing for a modular design can follow two strategies. Either to aim for a minimal complexity of the interfaces (low number of iw between two modules) or for reducing the number of interfaces per module.

Architectural options (AO) with few and simple interfaces are preferable from a modularity point of view. AOs with complex and many interfaces on the other hand are considered less feasible, and may be reason to dismiss the AO.

An AO with few but complex interfaces between modules may be candidate for merging clusters into multi-level modules. If all complex interfaces can be integrated into clusters, the AO as a whole can improve its modularity, and be moved from the top left to one of the lower squares in the 2x2 matrix shown in Figure 4. The many-simple case indicates several interfaces that in themselves are not very complex. It may not be reason for eliminating the AO, but is should be considered less fit for realizing the benefits of modularization in early stages.

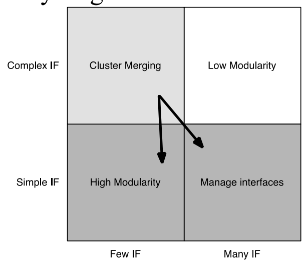

Figure 4. 2x2 matrix to characterize interfaces between clusters.

3. Functional modularization of a turbine rear structure (TRS)

To illustrate the above mentioned approach to clustering, a functional model of a TRS was created. The model is illustrated as an E-FM tree, shown in Figure 5. As a foundation for the clustering, the different leaf-DS are connected with iw.

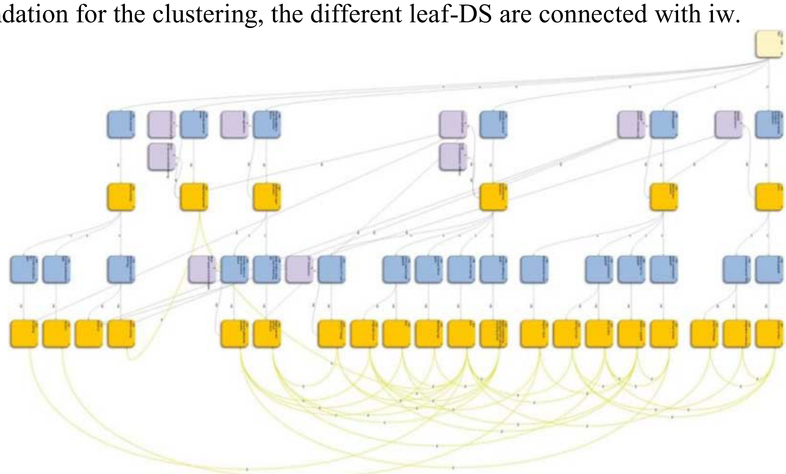

Figure 5. The EF-M tree of the Turbine Rear Structure, including several alternative DSs (yellow) for some FRs (blue).

From the functional model, which included several alternative design solutions, two instantiations were analysed. They differ mainly in the way the vane/strut structure is build up, with design A having the load bearing structure integrated in the vane shape, whereas design B seperates the aero- and mechanical functionality with a rod for structural loads and a faring for aerodynamic performance.

The iw from the EF-M tree were converted into a DSM, listing all DS and showing their respective relations.

Each module, which is seen as a greyed out square in the DSM, is constructed from DS elements and sub-modules. Their respective connections are managed inside the module.

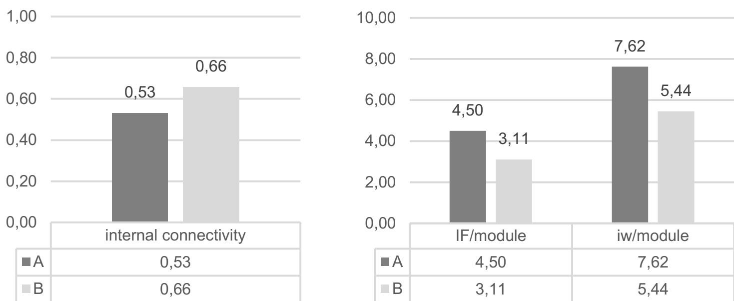

Figure 6. Internal (left) and external (right) connectivity metrics of the two example architectural options.

	Conical surface	Cone TRS flange	Oil tubing	Integrated generator	Active cooling	Bleed air	TRS LPT flange	Rigid hub and shroud structure	Hub	Hub surface	Sensors	Angular vanes	Vanes in gaspath	Integrated vanes	Shroud sufficiently resistant	Shroud surface	Mounting lugs	to mounting points
Conical surface	x									1								
Cone TRS flange	1	x							1									
Oil tubing			x															
Integrated generator				x	1													
Active cooling				1	x													
Bleed air						x												
TRS LPT flange							x	1	1									1
Rigid hub and shroud structure							1	x	1	1								1
Hub		1	1	1			1		x	1				1				1
Hub surface	1							1	1	x			1			1		
Sensors											x	1						
Angular vanes											1	x		1				
Vanes in gaspath												1	x	1		1		
Integrated vanes									1			1	1	x	1			1
Shroud sufficiently resistant														1	x	1	1	
Shroud surface										1			1		1	x		
Mounting lugs																	x	1
Rigid load bearing structure from hub to mounting points							1	1						1			1	x

Figure 7. Clustered DSM of architectural option A.

External relations are collected in interfaces. Inside the interface object all connections and the information concerning them to one module are collected. This approach to structuring should allow the modelling of the modular structure in an object oriented approach.

As shown in Figure 6, the clustering of design B is more consistent, in the way that it has a higher average internal connectivity of all modules, and also a lower external connectivity shown in a lower average number of iw per DS, and also lower average number of interfaces per module.

	Integration in fairing	Fairing on hub	Conical surface	Sensors	Angular vanes	Oil tubing	Integrated generator	Active cooling	Bleed air	TRS LPT flange	Rigid hub and shroud structure	Hub	Hub surface	Mounting lugs	from hub to mounting points	Vanes in gaspath	Rod	Shroud sufficiently resistant	Shroud surface
Integration in fairing	x	1	1																
Fairing on hub	1	x	1													1			
Conical surface	1	1	x										1						
Sensors				x	1														
Angular vanes				1	x														
Oil tubing						x													
Integrated generator							x	1											
Active cooling							1	x											
Bleed air									x										
TRS LPT flange										x	1	1			1				
Rigid hub and shroud structure										1	x	1	1		1				
Hub		1				1	1			1		x	1		1		1		
Hub surface			1								1	1	x			1			1
Mounting lugs														x	1				
Rigid load bearing structure from hub to mounting points										1	1			1	x				
Vanes in gaspath		1			1											x	1		1
Rod												1				1	x	1	
Shroud sufficiently resistant														1			1	x	1
Shroud surface													1			1		1	x

Figure 8. Clustered DSM of architectural option B.

4. Discussion

The model used in the approach aims to capture architectural options in early design phase in an effort to explore a large number of designs. Although based in immature knowledge about the design, it adds the benefits of modularization in an early phase of development.

The approach builds on existing theory and established design tools, such as EF-M modeling and DSM clustering. The suggested tools provide steps towards design automation of specific tasks in the concept development phase.

The example compares two alternative solutions against each other, and therefore only requires relative comparison of metrics. To automatically eliminate solutions based on their possibility to modularize would require threshold values for all metrics. However, the automation of such decisions is not the end goal. It is rather to automatically generate enough data so that the architect can make informed design decisions.

Using EF-M modeling to express concepts is quick and is easy. However, the knowledge required to accurately draw the iw-relationships should not be underestimated. If done accurately, the model supports modularization of the concepts, but the outcome of the analysis is sensitive to the modelling quality. All information has to come from the engineers' experience and ability to estimate system behaviour. This is especially the case for the development of new products, and less so for incremental development.

This paper does not suggest a new way of clustering, it rather makes use of the DSM clustering as a standardized format of assessing elements and interfaces. Yet, the quality of the clustering depends on the quality and purpose of the clustering algorithm. Thus a pivotal part is to identify a clustering algorithm that matches the purpose of the approach.

Though modularization theory presents a range of benefits in development, only some of those are targeted in this paper. There are possibly more benefits than the ones addressed here, and there are most likely benefits that cannot be achieved until the physical embodiment exists.

The example in this paper also neglects to take account of extreme results of clustering, such as on single module as output or multiple elements that could not be assigned to any module and are "free". This might be either managed by adapting the clustering algorithm, or by respective guidelines in the further design work.

It is also not yet considered how the next step in the design process is executed, and how the transition from functional to physical clustering is handled. This may be the topic of a future paper.

5. Conclusions

Modularization in concept phases as presented in this paper provides benefits to companies that may otherwise not be able to use modules in their development. It does so by applying functional modeling to model designs in early stages, and act as basis for clustering into functional modules, rather than physical modules.

The composition of the modules determines the knowledge need, task decomposition and design team composition for each module, whereas the interfaces between the modules identify communication needs. The clustering focuses on minimizing interfaces between modules, to minimize the need for cross-modular decisions.

The illustrating case shows how the approach is applied to a turbine part design process. The resulting clustering generates a number of modules within the product that can be used to introduce concurrency in the design process.

To assess the ability to modularize different concepts, a connectivity metric is proposed. It relates to the complexity of those interfaces that cannot be allocated to a specific cluster. These can be few or many, and simple or complex. The preferred architectural options should have few and simple interfaces, whereas simple-many and few-complex can be managed. The architectural options with many complex inter-modular interfaces may be discarded in favor of other architectural options.

The main benefit of the approach is that it provides structured assessment and exploration of different design concepts in phases where the design freedom is high, but the knowledge about the design is uncertain. It enables informed design decisions about functional modularity. This design phase is however confined by the low maturity of the models, which is why careful consideration needs to be made of how the models can be used, without introducing uncertainty that undermines any decisions built on the models. To create structures for managing knowledge in these phases, functional modularization may provide the necessary means to dividing the design work, and devising a feasible system breakdown.

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The Design Process Data Representation Based on Semantic Features Generalization

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Abstract. This article is about the approach to achieve of design decisions modifiability on the level of assembly units. The main feature of this approach is design parameters manipulation as the semantic attributes. This is achieved by the assembly process representation of consistent implementation design procedures. They are treated as basic operations set, united by object orientation with a strictly defined semantic content.

Keywords. automation, 3D-model, assembly, design activity, design solution, process constructing, product, CAD-system, modifiability, solid representation, multibody model, semantic fullness, process, design procedures

Introduction

The current stage of CAD-systems development is the design documentation, presented in the form of three-dimensional model [1] came to the fore. Such documentation is an electronic document in the 3D-model format. Several critical positive aspects (ease of manufacture and convenience of design documentation creating, design solutions visualization) cause other difficulties associated with different CAD-systems operation specificity [2].

Usually a huge number of changes made during of the design documentation production. It occurs for different reasons and requires timely change of the solutions obtained in the corresponding CAx-systems. It is necessary to transform constantly all 3D-models, including on 3D-assembly to account for these changes [3]. The standard approach to modification of assemblies [4] (editing parts in the assembly context) cannot be fully realizable. The reason is that the parts do not correlate with each other and there is no possibility to set associative links between the attributes of 3D-model parts [5]. Thus, the standard approach violates the integrity of the design solution, and therefore requires manual adjustment of it solution. For the designer, who is not the author of the project it will cause additional problems.

Therefore, the actual problem is semantic patterns selection offering the necessary functionality for controlling 3D-image design data, which provides uniquely correct perception of the engineer-constructor.

This article explores the approach to achieve modifiability of design decisions at a level of on 3D-assembly [6], based on its representation as a process consistently

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executes basic operations, incorporated in the design for object orientation procedure with a strictly defined semantic content.

1. Procedurally-Semantic 3D-Model Description

The lowest level of product design is designing parts that have one-body corresponding 3D-models within the 3D CAD concepts.

Part 3D-model Det^{3D} can be completely described by a construction tree [7] – streamlined design procedures provided the CAD-systems sequence as follows:

$$Det^{3D} = \sum_{i=0}^{n} des.proc_i \left(\sum_{k=0}^{m} des.par_k, \sum_{j=1}^{(i-1)} int.con_j \right), \quad \textbf{(1)}$$

$des.proc_i$ – design procedure, which has ordinal number of execution with a unique set of design parameters $des.par_i$ and relationships with other procedures $int.con_i$ that exist in the form of mathematical and logical expressions.

Information 3D-image parts Det^{3D} can be viewed as a structured set of project stages – a set of procedures described by the formula (1), combined in a fixed semantic unit [8], which formally as follows:

$$Det^{3D} = \sum_{i=0}^{n} \sum_{j=1}^{m} des.stg_i^{Obj_J}, \quad \textbf{(2)}$$

$des.stg_i$ – the design stage of construction of the j-th object Obj (object is a structural element of the details that has clearly perceived the physical sense).

Design stage notion is fundamental in our research: it is control of 3D-objects construction process in the details allows to parameterize the 3D-image of the product while maintaining the initial set of the discriminant.

Formally the design stage is described as follows:

$$des.stg_i^{Obj_J} = \left\{ \sum_{i=0}^{n} des.proc_i \left(\sum_{k=0}^{m} des.par_k, \sum_{j=1}^{(i-1)} int.con_j \right), M_{des.par}^{Obj_J} \right\}, \quad \textbf{(3)}$$

$M^{Obji}{}_{des.par}$ – is a set of object Obj attributes. Obj – set of design parameters that fully describe its 3D-image information, and perceive semantically clearly. Each attribute of an object from a plurality of $M^{Obji}{}_{des.par}$ has a relationship with the local parameters of design procedures in accordance with a predetermined design algorithm.

The difference between the Formula 3 and Formula 1 in that formula 3 identifies “discriminanst”: attributes of the object – the parameters, the source for its construction. Handling these parameters does not require knowledge of algorithm development. Here need only knowledge of the subject area – the structure of the object and the part itself. Moreover, compliance with the design conditions of the system allows us to implement a tree structure form design solutions, allowing to generalize the objects in a single class on the basis of their semantic content.

On the basis of formulas (1) – (3) we can state that the 3D-model of the part may be represented as a set of objects M^{ObjJ}, having clearly perceived within the meaning of the part that can be represented as a formula:

$$Det^{3D} = \sum_{j=0}^{m} M_{Obj_J}^{3D} \left(M_{des.par}^{Obj_J} \right), \quad \textbf{(4)}$$

The basic object is a "Basis" or " Template" for the future design product: its discriminant – design parameters within the domain and technical specifications; He is the source for all other objects, and is associated with the original set of design parameters. Any desining always starts with its definition and formation.

Decomposition of process described by the formula (2), on the basic operations that are part of design stages, allow establishing associations between the attributes of objects, providing a structural and logical integrity of the design solution. This allows to control the assembly 3D-model, using a single set of input parameters.

Procedural representation (2) describes a 3D-model as non a complete solution, but as the process of its formation [9], as it considers consistent contribution of each stage in the final decision. The process of building a 3D-model conveniently considered as part of the IDEF methodologies family for visual display of the interaction design stages. Thus, four types of relationships can fully define the process; These include:

- *Input* – the source data. Technical task can act as an input (set of attributes point to the origin, and others.)
- *Exit* – execution result. It is structurally complete information 3D-image set of intermediate design parameters, 3D-model of the element, and others.
- *Control* – a set of conditions, rules and restrictions. It includes the state and industry standards for designed products, information and technical documentation.
- *Mechanism* – execution tool. As a rule, the mechanism is the user – a design engineer and CAD systems.

Presentation of the process of building a 3D-object within the IDEF methodology allows to clearly establish the types and the associative relationships between the project and the procedures included in their composition design operations, then it is necessary for the program implementation

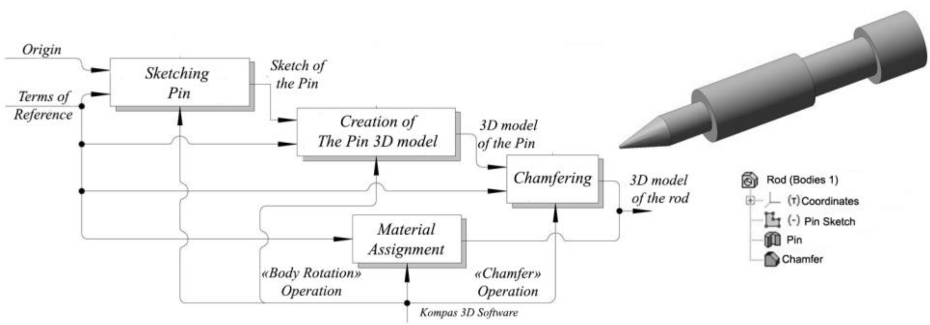

Figure 1. 3D-model of the rod and IDEF0-model of its building process.

As illustrated (in Figure 1) input (source data) – Terms of Reference, the point of origin (for spatial reference) output – the result of the design procedures: Information 3D-image.

Adding a change in one of the stages of design (internal or external) will result in a corresponding change of the output stage, as well as to a change of input data for all subsequent stages. Thus, the design solutions structural and semantic integrity fixing is carried out. Modification of assembly unit 3D-parts is supported at all stages of the its formation process.

2. Assembly 3D-model System Representian

Assembling is a 3D-system parts and subassemblies, which in terms of 3D CAD are complete structural elements. In general, it can be described structurally as follows:

$$Asm^{3D} = \left\{ \sum_{i=0}^{n} Det_i^{3D}, M_{con.}^{Asm}, M_{des.par}^{Asm} \right\}, \quad \textbf{(5)}$$

Asm^{3D} – assembly 3D-model of the product, $M^{Asm}{}_{con.}$ – set of pairings between a set of component parts, Det^{3D}, $M^{Asm}{}_{des.par}$ – set of assembly attributes.

Figure 2 shows: assembly 3D-model of coaxial contact and the model tree. There are only pairing options. This means that the parameterization of assembly is reduced to operating parameters of the interfaces or location of the components in space.

Assembly is controlled by manipulating the values describing its attributes, which can be reduced to two variants of its modification: changing the set of component parts (quantity), and the change in their relative position. In both cases, access is not available for editing the details themselves. This is so both in the assembly their 3D-image is strictly defined.

Mates tie to the structural details of the objects to each other. It determine only the positions of these parts in the space (both static and moving range), making the system components integral in a predetermined structure.

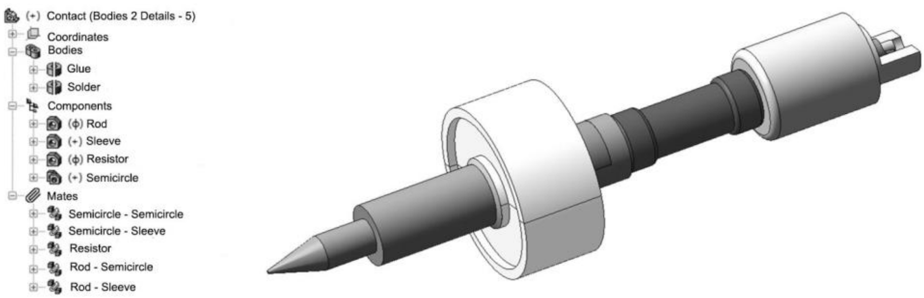

Figure 2. Assembly tree and its 3D-image.

As a result, at the classic sense, the assembly cannot be considered as a process for the following reasons: parts are complete structural elements and the sequence of mates installation has no effect on formed decision. And the processes of creating 3D-model of component changes in will cause a restructuring of the assembly unit, usually accompanied by a number of errors. So, need a different way to describe the assembly.

3. The Approach to 3D-Assembly Model Procedurally-Semantic Description

Presentation of the assembly unit as the process is made possible by shifting the level of model decomposition from the level «3D-Building" to the level of «3D-Detail" which is accompanied by two critical transformation:

- The assembly model is considered as a complex 3D-model of all parts – as a set of objects (separate solids), it allows to keep the processes of construction of each of its components.

- Details – assembly components are treated as objects in the context of a single piece, that allows to establish associations between their attributes, and transfer their design parameters describing the level of the assembly unit.

Thus, a complete set of components, including the process of their construction and ready for detailed analysis and processing is present in a single file. This file allows to fully describe the process of formation of the design solution, while maintaining relevance with decomposition to the lowest levels, and at their change.

Procedural model of on 3D-assembly transformed into a multibody part is a consistent association of constructing processes every part of components:

$$Asm^{3D} = \sum_{i=0}^{n} Det_i^{Obj_i}\left(M_{des.par}^{Obj_J}, M_{des.par}^{Asm^{3D}}\right), \qquad \textbf{(6)}$$

Det^{Obji} – a kit of parts components represented as an object in the context of a multibody part. Each of these parts is a function of parts the attribute values $M^{Obj}{}_{des.par}$ and the assembly itself $M^{Asm}{}_{des.par}$.

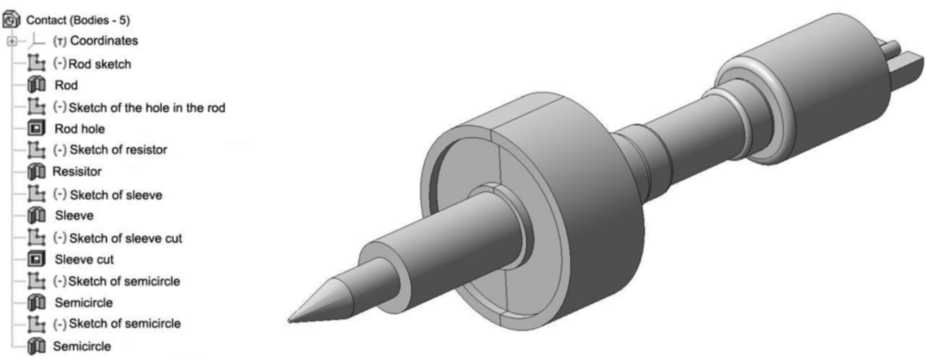

Figure 3. 3D-assembly is converted into 3D multibody-part.

Figure 3 shows the assembly unit of the rod shifted to the level of 3D-part. As can be seen, multibody parts contains 7 solid bodies (5 of them – correspond parts-components). Fixing component (solid bodies) on a single level, allows to select discriminants of projected assembly. Source data are following from them: the type, the length of the rod, type and value of the resistor and the value of the wave resistance; all other design parameters are obtained by calculation.

Thus, it becomes possible to associate the assembly of components that provides its full parameterization and interdependent components. As a result, it provides its modifiability in automatic mode by changing the the describing attributes the assembly itself as well as by changing the the parameters of the local the components.

4. Program Implementation

Program implementation of the proposed approach is based on the use of the Open CASACDE Technology (OCCT) platform as follows: structural analysis of the designed product stands out a set of used design operations from the library OCCT [10], which are encoded in a consistently executing protocol – the object 3D-model creation basic operation. This operation provides its attributes for a complete determination of the designed product.

5. Conclusion

Fixing assembly components based on submission of solid bodies (objects) on a single level, allows to select discriminants projected assembly unit, connect them to define the initial set of data that will be strictly defined semantically and will allow to operate the 3D model of the product, in terms of subject area concepts which applies the product.

Assembly unit description by system patterns allows to select discriminant designed product, link them to determine the source of the data set that will be strictly defined semantic information and enables you to control 3D-imade, in terms of subject area to which the proposed facility.

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Part 4

Engineering for Sustainability

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Transdisciplinary Engineering: Crossing Boundaries
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3D PDF-Assisted Planning for Disassembly and Recycling of Complex Products

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Abstract. Manufacturing companies nowadays are more than ever compelled to adapt to the challenges of constantly changing conditions in the product creation process. The exchange of digital data and data processing are in the foreground in many processes from initial idea to disassembly and recycling. For this purpose, especially in product development and in downstream processes, versatile data formats are needed which are able to enrich 3D product data with additional information. Subsequently, the 3D PDF is a potentially suitable format to support a variety of applications. It offers not only the ability to visualize 3D data without installing or licensing a CAD system, but also allows the data to be dynamically adjusted, commented and animated in a template container. By means of digital rights management, a know-how protection is provided in the use of 3D PDF, which has a high priority in many industries of the manufacturing sector. In this paper, a concept for the use of 3D PDF is presented regarding a defined workflow for disassembly and recycling within the product creation process. For achieving this, an analysis of existing use cases and associated processes is necessary. After having identified an distinctive field of studies with the help of the model, it is to work out a new use case. Later in the paper a workflow is developed and finally a prototypical example of the 3D PDF document is implemented.

Keywords. Design for X, Disassembly, Recycling, Sustainability, Product Creation Process, 3D PDF

Introduction

Modern industrial companies are forced to adapt their business processes to the progressiveness of IT technology. This optimization to agile processes includes the entire product development process, starting from product planning and requirements management until dismantling and recycling of the product [1].

In general, recycling is defined as the "return of production and consumption waste into the economic cycle." This includes not only the recycling and reuse of waste material, but also the further use and recycling of used parts in new ways [2]. These terms are to be distinguished. To ‚further use' means to utilize already used products for any other than the original purpose. This contrasts with the reuse, whereby the product is used for the same purpose [3]. This includes the removal of functional parts of a vehicle to be scrapped and their reinstallation in another, still drivable vehicle. Recycling refers to the reuse of waste materials and production waste in a similar production process. One example for this type of recycling is to melt down old vehicle parts, in order to reuse the resulting raw materials for new vehicles. The last type is

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recycling, whereby waste material and production waste is integrated within a production process that they have not yet passed through [4]. For example, old car seats are shredded to use the fibers in a new process for the insulation [5].

In the automotive industry prevail legal requirements for the disposal and recycling of car wrecks. In a directive of the European Parliament automobile manufacturers are encouraged to „avoid waste as far as possible“. Therefore the „reuse and recycling [should] take precedence“. To make this possible, all EU Member States have to take measures in order to take back end of life vehicles for processing and recycling [6]. Thus, automobile parts do not have only to be dismantled but also be sorted by criteria such as material, reusability and processing ability. The dismantling of hazardous substances, such as the built-in airbag pyrotechnics must be clearly described for recycling companies to minimize the potential danger during further disassembly [7].

The starting point for the case study is a company in the field of mechanical engineering that offers its customers, among other things, maintenance contracts [8]. The company sells several products, each of which contains detailed service documentation. These include 2D drawings of the individual product and various bills of materials (BOM), with which, for example, spare parts can be ordered. In addition, a service manual even includes instructions for the assembly and disassembly of different components in individual steps with appropriate drawings [9][10].

For the creation of the service documentation, the aggregation of engineering design data across-the-board and the processing of this data are necessary. The design engineer team has to revise its 3D models, to create screenshots and to adjust them to the desired assembly / disassembly steps. Product Manufacturing Information (PMI) and annotations must be processed appropriately. BOMs have to be extracted and reformatted from the product data management (PDM) and other parts lists from associated XML files. Once the data is complete, the service documentation with more than 500 pages can be printed and distributed to the authorized service staff.

The process of creating an assembly instruction often takes a long time, since many arrangements between different departments are needed. In addition, the process could still yield some disadvantages: If errors are found in the documentation, an updated version must be created, printed and distributed. Due to its extent the service documentation is often confusing and only slightly supports service staff when ordering replacement parts.

To make the creation process and the usability of the service documentation more efficient, providing a tool for the automation of the process is necessary. To create and utilize 3D PDF contributes the optimization of the process of product service.

1. Analysis of the existing use cases for 3D PDF

In order to evaluate and classify the existing use cases, evaluation criteria need to be established first (section 2). In addition, a distinction of use cases is necessary to determine the individual functionalities that are provided by the use of 3D PDF. In this pivotal section existing use cases are analyzed, structured and classified into a self-developed model by means of a literature research and expert interviews. In order to do that, a horizontal categorization into the product life cycle has been defined and a vertical categorization, based on the use case goals was implemented [11]. The purpose of this method is to obtain an overview and simultaneously identify gaps, where 3D PDF still has the potential to support additional phases in the product lifecycle. Section

3 summarizes the results of the analysis, and describes in which field the new use case impacts the product life cycle.

Regarding the issue presented here, the collected use cases describe existing application models and partly not yet reached ways in which the 3D PDF format can contribute to processes in the field of mechanical engineering [12]. The use cases assist in product lifecycle management (PLM), by optimizing individual processes and facilitating a more effective communication between all parties involved [13]. The case study presented in section 4 shows how complex service documentation on paper can be replaced by drawing free 3D PDF documents, thereby not only providing more flexibility, but also supporting the user in his work. In a "big picture" (Figure 1) this use case would be classified as the use case service documentation.

In the case study, the data for the embedded BOM from an XML file is read and only associated to the 3D data during the actual creation of the respective 3D PDF. The resulting file could also consist of an assembly instruction in addition to a 3D PDF. This instruction is adopted from screenshots and descriptions included in the document previously created and automatically transferred into another document using the server-based solution. To rank the relevance of the existing use cases, they were divided into different levels according to their complexity and accuracy. For horizontal classification according to the level of detail three levels of goals are used that the use cases can be geared to.

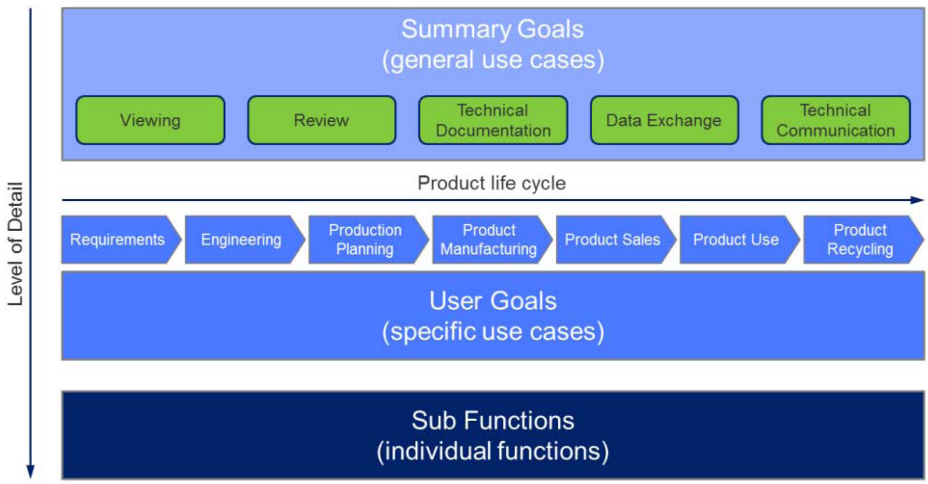

Figure 1. Schematics for Use Case Structure

2. Requirements for the use case "3D PDF recycling documentation"

„End of life vehicles consist of lots of toxins, such as brake and battery fluids, CFCs, lead and oil – as well as of recyclable materials such as steel, copper, light and precious metals or glass and rubber [14]. The industry has a major vested interest in putting as much as possible of these materials back into circulation [15]. Since the greater the supply, the lower the prices of the materials from which, for example, new cars are produced [16]. On average, each car wreck weighs almost a ton, this results in a total of up to 500,000 tons of scrap metal – every year." [17]

Already in 1994, the Recycling Law was adopted in Germany, in order to reduce waste. This includes the promotion of sustainable dealing with natural resources, the protection of humans and environment and the encouragement for the recycling of waste materials [18].

In 2000, the European Parliament has published a directive to „reduce the environmental impact of end of life vehicles and thereby contribute to the protection, preservation and quality improvement of the environment and energy conservation, [...] to insure the proper functioning of the domestic market in order to avoid distortions of competition in the community.“ [6] At the latest by 2006, the reuse and recycling of old cars should reach at least 85 percent, and since 2015 it has to rise to at least 95 percent. Subsequently, the automotive manufacturers need to increase their efforts to provide recycling capabilities during the design and manufacture of vehicles.

In addition to the legal requirements, the automotive industry has a vested interest to reuse as many materials as possible in order to ensure the raw material supply. „Particularly end of life vehicles are a major source for the acquisition of secondary raw materials. The objective of the BMW Group is to close material cycles and to contribute to the conservation and protection of natural resources.“ [19]

An early planning of recycling capabilities is crucial, because „in the early phase of product development there are specified not only 80 percent of the cost of a product, but rather more than 95 percent of the materials and manufacturing processes and hence the resulting environmental impact.” [20] Thus, it often causes issues in various phases of the product life cycle, such as during construction and recycling. This results in a trade-off between the short-term objectives of the various actors. For example, during design phase a simple solution is preferred for assembling components by adhesive bonding, but this prevents an environmentally friendly disassembly [21].

The continuous developments in the automotive industry also require a more efficient planning effort during the recycling and waste management phase. For example, the amount of batteries will increase due to the frequent dissemination of electric cars. „In particular, the extraction and processing of metals used in the batteries is related to the emissions of greenhouse gas and pollutants. […] Therefore, and also for economic reasons, it is essential to develop and establish efficient recycling processes for disused batteries as soon as possible.” [22] Furthermore, alternative fuels, such as gas, require special recycling processes, as additional security risks originate from dismantling the gas facilities.

Part of the development of new car models is to meet the increased demands of safety and crashworthiness. Therefore, inter alia, the number of installed airbags in cars rises. Given that in the 80s airbags were accessory equipment for luxury-class sedans, up to 15 airbags are installed in an average car nowadays [23]. The disposal of these pyrotechnic units is therefore becoming increasingly important for new car models.

Another field that is increasingly widespread in the course of modernization is the sector of electronic components. Here, besides long harnesses many boards with appropriate materials, such as copper, or rare earths are used. Due to the growing worldwide scarcity of raw materials, it is considered even more important for companies to systematically extract and recycle these materials [22] [24].

„The demand of raw materials of the German automotive industry has grown steadily over the past year-tenth. The reason for this is not only determined by increased production figures, but also by the increasing vehicle weight across all segments.” [25]

Another indication of the growing need for more efficient recycling processes within the automotive industry is the fact that air conditioners are now also an integral part of the standard equipment in small cars. Thus, in addition to other liquids such as gasoline, oil or brake fluid the coolant must also be drained and disposed of when recycling an old vehicle. In order to create a template for the recycling process of old cars this paper follows the models described in the documents published by BMW [19].

3. Concept for creating a 3D PDF recycling document

During the creation and use of a 3D PDF recycling document various actors are involved that occur in several successive phases, as depicted in Figure 2 with the developed phase model.

The first actor in the use case “3D PDF recycling document” is the design engineer. With the aid of 3D CAD software he designs the vehicle, is already vigilant about recyclability of as many materials as possible used in the car and he develops processes to extract them back from the vehicle. Depending on the manufacturer, collaboration with the production planner is possible that is responsible for the creation of assembly instructions. However, since the design engineer is doing the main task, only he is listed [26]. To avoid transferring engineering design knowledge in the recycling documentation, the 3D model needs to be revised before its integration. This involves a certain concept that focuses on the individual disassembling steps. Thus, modules that are to be removed as a whole and parts with danger potential should be highlighted.

The second actor is the evaluative disassembler of a recycling plant. He receives the car wreck and has the opportunity to obtain the appropriate 3D PDF recycling document. He is authorized to use the document and is allowed to open it by entering a password. Then he updates the basic vehicle data with additional vehicle-specific usage data, such as the lifespan, the mileage, etc. It is even possible to record particularities for the subsequent disassembling, for example, the use of foreign manufacturers’ parts.

The enhanced recycling document and the respective vehicle are then handed over to the third actor, the executive disassembler in the recycling company. He is able to register and to record possible peculiarities and his assessment of the reusability of dismantled parts during the disassembly process.

The fourth actor is the supplier for used parts. He receives the disassembled components that might be reusable in order to preprocess them or to sell them directly. Among the parts, he gets an assessment with additional information about the respective part in a 3D PDF that has been enriched with information of the disassembler. The provided information helps the decision making to reuse or recycle the respective parts. For example, parts from damaged vehicles could be highlighted and, thus, tested for cracks in the material in order to guarantee a safe reuse. To prevent the transport of not required parts, the 3D PDF can be send in advance during this process step providing an overview of all available parts to the supplier of used parts.

Concurrently, the fifth actor receives the remaining stripped vehicle and core scrap among with additional information about the end of life vehicle, such as data referring weight and materials comprised. For this actor the recycling process is prioritized, whereby the remnants of the vehicle are crushed in a shredding mechanism and the resulting raw materials are separated. The recycling process could be facilitated using the information provided in the recycling document. In this way, determining the particular processing steps would be easier; for example, a presorting step could be implemented in the process. An integration of the 3D model for this process step is not absolutely necessary, which is why the handover document plays a subordinate role.

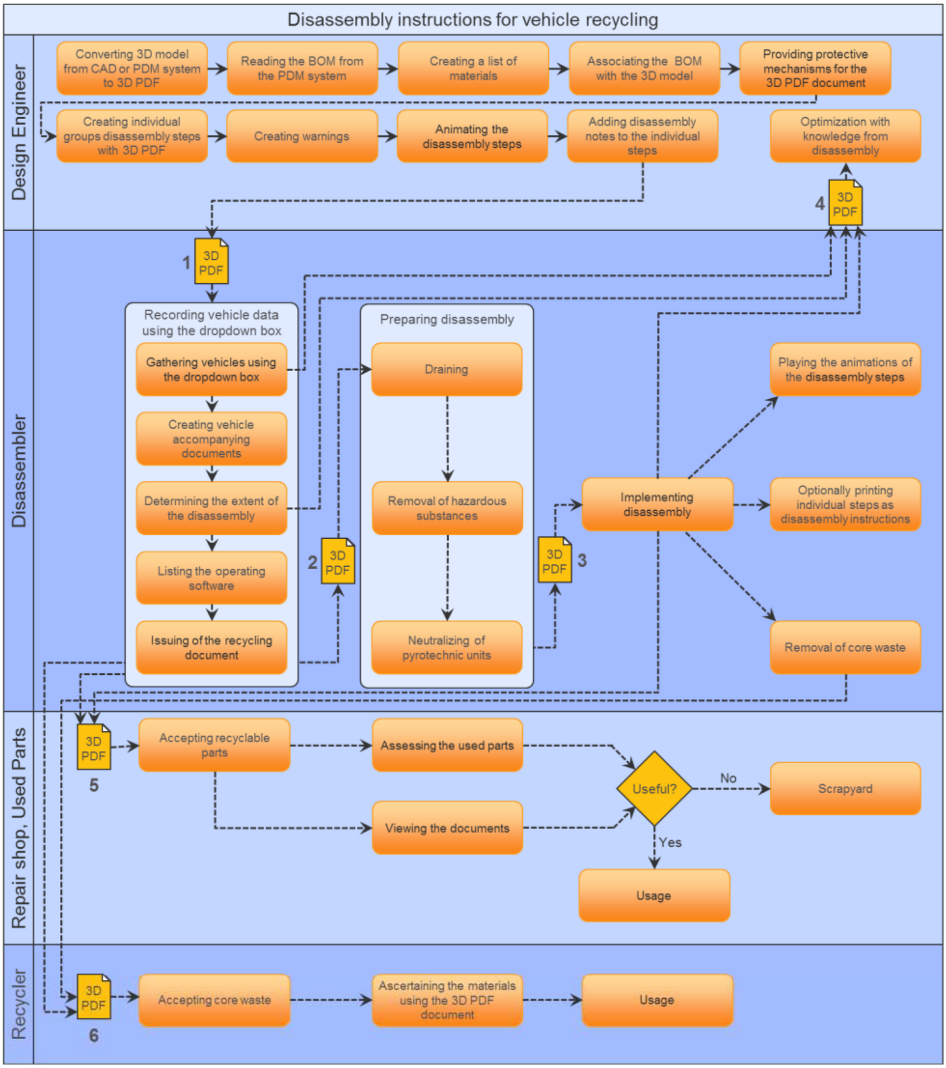

Figure 2. Workflow for creating the 3D PDF recycling document

Using the defined phases and actors, the necessary transfer documents have been defined. Hence, an adapted workflow can be developed in this section that defines all the data for the recycling document. In order to get an overview of the roles of the different actors and the data generation, the swim-lane diagram in Figure 2 was created. The diagram represents the central workflow for creating and using the recycling document, wherein the digits 1 to 6 constitute the different handover documents.

In order to develop an industry-oriented approach, a data source must be defined first: a PDM system, individual Excel spreadsheets, XML documents or database systems. For the use in a 3D PDF document, the data must be converted in the first step for the creation of the recycling document as described in Table 1.

Table 1. Implementation of the functional requirements of the recycling document

#	Requirement	Implementation	Status
F1	3D model of the product	The handover documents 1, 2, 3 and 5 are providing the integration of the 3D model, which is converted to a 3D PDF by the design engineer.	✓
F2	Animations	The creation of animations should be carried out by the production-planning department using 3D PDF Pro.	✓
F3	Description of individual steps	The description of individual step will be carried out by the production-planning department using 3D PDF Pro.	✓
F4	Coloring of materials	The coloring should be done with the aid of the stored materials in the BOM. A process step to automate the color-coding must be implemented.	✓
F5	BOM	The conversion of any format into JSON needs to be implemented and integrated with the workbench in the process.	✓
F6	Document overview	This requirement is implemented by adding a document overview to the first page of the 3D PDFs. The implementation is located in the template.	✓
F7	Associating BOM and Model	The associating is automated based on a unique ID, following the 3D conversion.	✓
F8	Warnings	The design engineer can insert warnings to the finished 3D PDF. For that, the template provides text boxes and a color-coding in the BOM.	✓

To export the 3D model from the 3D CAD system used, it is generally only one file needed in addition to the 3D PDF Converter or the server solution of 3D PDF Generator. For a correct representation of the model, a custom template must be created that determines at which point the 3D content is displayed and that implements required functions. The embedding of the 3D model is the central step and fulfills the functional requirement F1.

For importing the BOM, it is necessary to convert the source information in a JSON object. The conversion from any format needs to be implemented and integrated with the help of Adobe LiveCycle Workbench into the overall process of converting. The import and conversion is a prerequisite for the fulfillment of requirement F5.

The list of materials used derived either directly from the 3D CAD system or from the PDM system used in the company. To integrate the list, another conversion is needed to transfer all the necessary data into the appropriate JSON object for the associated 3D PDF. At the same time the color-coding of the parts in the 3D model can be made. For this purpose the colors for important material properties are defined previously. The coloring fulfills requirement F4.

The associating of the BOM and the 3D model (requirement F7) is done during the conversion process. In this step the data are compared on the basis of unique IDs. To carry out the comparison, firstly the list must be converted to an appropriate format. Since the data is customer-related and very diverse, no standard procedure can be used. It is important that either the BOM refers to the 3D model via ID, or vice versa.

The last step of the workbench process is to provide the created 3D PDF document with protective mechanisms. For this purpose, the Digital Rights Management module is suitable which is managed using the Adobe LiveCycle Server. An integration of protection mechanisms in the 3D PDF meets the non-functional requirement.

In the same process the Reader Extensions of the document, could be enabled. Its activation allows users to use functions that are initially only available in Acrobat Pro. These functions include the possibilities to import and export data, to customize form fields, to insert attachments and to save the document.

To prepare the vehicle data for the disassembly, it is necessary to create groups and disassembly steps for each vehicle model. The production-planning department can carry out the preparation, since this department is also engaged in the assembly where many process steps are similar.

4. Implementation of a sample workflow

The document contains a 3D model and a BOM. Further data have been inserted manually. The model data include the make of the vehicle model, the model name and the component currently displayed. Additional document data is available, such as information about the type of document, a document ID and a revision ID. To allow the design engineer to make modifications directly, a dropdown box is integrated into the 3D PDF. This dropdown box allows specifying the properties of the mechanical components, including information about reusability and recyclability.

The first step of the process is to create the 3D PDF document using the Adobe LiveCycle Server in combination with the installed 3D PDF Generator. Here, the previously developed workbench process is already integrated. Once the 3D PDF is created, the design engineer can work with it. One of his tasks is to identify parts to define their way of disassembly.

For the development of customized 3D PDFs, Acrobat JavaScript is used, based on version 1.5 of JavaScript. The BOM can be imported e.g. from an Excel document into a JSON file. Then, the converted files are read to insert them later in the writing process directly into the 3D Script. The data is previously selected, since only some of the columns from the table are crucial for the 3D PDF. This includes the part name and the material. These steps are done by hand in the current implementation, but can be automated in the future on the basis of the flexibly designed workbench process.

The creation of 3D PDF takes place after the step previously described. After creating the document, the previously read list is optimized and imported into the 3D PDF. At the end of this process another step, (Apply Usage Rights) is realized where the Reader Extensions module equips the created 3D PDF with additional rights. This includes the ability, to save the customized PDF.

The BOM of the appropriate model was available in the CAD software. Thus, it has been exported firstly to use it in the 3D PDF. There were several ways to export the BOM, such as a text file. In order to obtain the data as well organized as possible, an Excel spreadsheet has been selected as the export format. Data such as BOMs are available in table form in PLM systems. This type of export represents a relatively accurate workflow for productive solutions and allows the subsequent implementation.

Various requirements from Table 1 are met within the created sample document (Figure 3). These include F1, the embedding of the 3D model, F5, the integration of the appropriate parts list and F7, the realization of the interactive associating of BOM and 3D model. Requirement F4, the color-coding of different materials has been adopted only partially. The basic functionality of the coloring of individual components is already feasible, but those settings cannot yet be saved persistently.

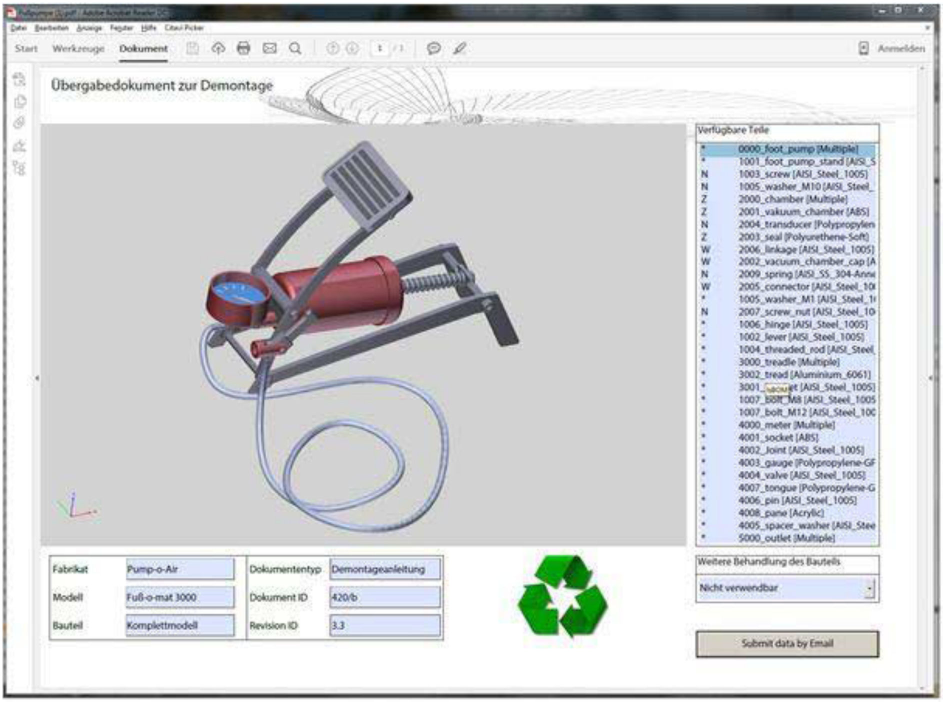

Figure 3. 3D PDF sample document

5. Conclusions and Outlook

The objectives of this study were to find a use case for the topic of 3D PDF in the product development cycle, to define a workflow and to develop an appropriate concept. By developing the concept of preparing a recycling document, this goal was achieved. Furthermore, it was planned to develop a prototypical sample document, which is described in the last section of this work.

In this study, a model was developed in order to obtain an overview of existing use cases and classify them during the analysis phase. This analysis shows the fields of study where 3D PDF still has potential that has not been exploited sufficiently. The result of the analysis was that the product life phase „Recycling“ was not sufficiently pronounced and the workflow to be developed will be located in this field. Subsequently, basic research was described and requirements for the appropriate use case were collected. Using that knowledge, it was possible to develop a concept that demonstrates how 3D PDF technologies can contribute to streamline the recycling process of end of life vehicles. The exact procedure, starting from the creation of the 3D data until the application of the document, was developed and described precisely.

Based on the developed concept, a prototypical 3D-PDF was presented which constitutes a part of the extent of the intelligent recycling document. The created 3D PDF template provides a basis for future realizations. In order to implement future developments efficiently, the template was designed as flexible as possible. The objective of this further development is the implementation of all of the derived requirements.

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Models of Impact for Sustainable Manufacturing

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Abstract. Design for Sustainability (D4S) and LifeCycle Assessment (LCA) methods usually focus on one single aspect of sustainability at a time (e.g., environmental issues, ergonomics or costs) and are usually applied when the industrial system is already created, so that only corrective actions can be taken. In this context, the present research highlights the need of predictive methods to design sustainable system, able to provide an early holistic assessment from the early conceptual stages, and defines a set of models of impact able to assess all aspects of sustainability (i.e., environmental, economic and social) by proper key performance indicators (KPIs) from the early design stages. An industrial case study is presented to show the application of the proposed models on industrial manufacturing systems and demonstrate their validity in estimating the global impact on sustainability, including also human factors.

Keywords. Design for Sustainability, Design Methods, Sustainable Manufacturing, Human Factors, Lifecycle analysis, Key Performance Indicators (KPIs).

Introduction

In numerous countries the actual economical growth is triggering environmental and social problems, pushing companies to adopt Design for Sustainability approaches (D4S). However, according to modern Sustainability Assessment (SA) practices, companies are called to optimize the use of any kind of resources and consider the mutual impacts of their choices on three dimensions: profit, planet, and people [1]. However, application of SA in industry is mainly based on ex-post analyses to monitor the existing conditions on the basis of Life Cycle Assessment (LCA) or Discrete Event Simulation (DES) [2]. As a consequence, actions are usually taken after the design stage, when products and/or processes are already developed [3-4]. In this context, the paper presents a set of key performance indicators (KPIs) and models of impact for early SA to be applied from the early conceptual stages, according to an analytic estimation approach. Indeed, industrial systems are particularly challenging due to the numerous aspects integrated into a single product and the transdisciplinary nature of problems. The goal is providing a quick and easy methodology to support designers in early SA of their products and systems in order to easily identify optimization actions to make the products more sustainable. The main paper contribution is the definition of structured models and KPIs to carry out a transdisciplinary SA, merging economical, environmental and human aspects, from the initial design stages in order to prevent low sustainable solutions by their timely optimization. The main challenge is to carry out

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such analysis from the early stages of product development, where systems are not already created so few information are usually available. Up to now, the models have been defined for manufacturing and production stages, but the same approach could be extended also to the other product lifecycle stages (i.e., use, end of life).

1. Research background

A broad range of different approaches is described in literature about SA. Based on evidences from real world, companies are pushed towards Sustainable Manufacturing (SM), based on the balance among environmental, economic, and social objectives [5]. Nevertheless numerous examples demonstrated how the adoption of sustainability principles can gain competitive advantages for companies [6], concrete benefits can be achieved only when the SA is introduced during the preliminary design stages, before product creation, optimizing the solutions in short time, and avoiding numerous engineering changes and optimization loops [7]. One of the most common approaches to SA is Life Cycle Design (LCD), which considers the entire lifecycle 'from cradle to grave' and the related impacts at each phase, from resources extraction through pre-manufacturing, manufacturing, transportation, use, recycling, and ultimately, disposal. Usually LCD includes the definition of key indicators to assess performances (e.g., functionality, manufacturability, serviceability, environmental impact) [8]. Different methods have been developed for these purposes: Life Cycle Assessment (LCA), that sums the environmental impacts generated during all phases of product lifecycle [9-10]; Life Cycle Cost Analysis (LCCA), that associates total cost to all lifecycle activities [11]; Social Life Cycle Assessment (sLCA) addressing the social dimension [12]. Some researches have coupled LCA, LCCA and sLCA analyses in different industrial sectors [13-15] and faced different aspect, such as lifecycle cost or human-related aspects [16]. In this context, several studies demonstrated the importance of adopting a holistic approach including the three areas of sustainability (i.e., plant, profit and people) in order to increase product quality, customers' satisfaction, and global competitiveness in order to increase the market shares [17]. However, a literary review about SA in industry, especially in manufacturing, highlighted the lack of robust frameworks for early assessment to be applied from the preliminary design stages. Considering the publications on international journals during the last ten years on Scopus databases, we found that the majority of research works refer to environmental-related aspects, and a good number refer to cost assessment. Only few works deals with social and human-related aspects. Four main methods for SA have been also compared: Environmental Impact Assessment (EIA), Human Development Index (HDI), Environmental Footprint (EF), and Life Cycle Assessment (LCA) [18]. A framework for the integration of different SA methodologies has been recently proposed [18]: it considers Multi-Criteria Analysis (MCA), Cost Benefit Analysis (CBA), EIS, Strategic Environmental Assessment (SEA), LCA, LCC, sLCA, European Social Impact Assessment (EuSIA) and Life Cycle Sustainability Assessment (LCSA).

Furthermore, numerous indicators have been defined during the years about SA of industrial products. A comprehensive overview has been recently provided by [19]. Few studies considered contemporarily the three areas of sustainability, but proposing a late assessment on existing plants and projects. Only Morbidoni et al. [20] proposed an early SA, but analysis is limited to costs. About social aspects, an interesting study [16] estimated the impact by considering injured worker's rehab, replacement of the operator with a new employee, and know-how dispersion in case of replacements. About physical stress analysis, the most common methods are REBA, RULA, NIOSH for the static tasks, OCRA and OWAS for the repetitive tasks. In most cases Discrete Event Simulation (DES) is used to segment the activities performed into sub-activities whose harmful level can be easily inferred. However, such methods generally require high level of detail and real process monitoring, which exclude their application to preliminary design stages and make it difficult and time-consuming for industry. From the literary review, two main issues in early SA have been identified:

- lack of practical guidelines to merge environmental assessment with cost and human-related issues assessment;
- lack of practice method to anticipate the assessment to the preliminary design stages, since impacts are usually evaluated "ex-post" on real plants or systems, once they have been already created and usually are currently working.

2. The research approach for sustainable manufacturing

The study proposes an analytic approach for the early SA of industrial products and systems based on a set of KPIs and a feature-based approach to fasten the assessment and make it suitable for industry. Indeed, it is based of the analysis of 3D product models features and their association to manufacturing and assembly processes, necessary to realize that shapes, in order to fasten and automatize the SA and make it possible also from the preliminary design stages. The approach combines three analyses: Early Environmental Assessment (EEA), Early Human Assessment (EHA) and Early Cost Assessment (ECA). For each of them a different set of KPIs is defined, and a set of models of impact for the KPIs measurement.

In particular, the early assessment is based on the recognition of the manufacturing processes started from the analysis of the product features. It is based on a quantitative estimating technique and, in particular, adopts the feature-based analytic approach as proposed by [21]. Such an approach allows to link geometric and non-geometric features to technological and assembly features in order to predict the following manufacturing process. Recognition is based on the decomposition into basic features and the correlation between geometrical features and process features. Thanks to this association, the product design can be analyzed and related processes can be inferred according to a set of pre-defined list of sub-processes. This association is possible thanks to a proper formalization of the process knowledge and the merge between geometrical data and logical information (i.e. design requirements, system configuration, technical specification, plant features, company best practices, etc.). Such an approach can be adopted manually or, more conveniently, automatically by a proposer software toolkit. Finally, processes are matched with machines' tasks, operators' actions, etc. thanks to a set of scenarios (respectively for manufacturing, use and end-of-life phase) that represent how the entire value chain (made up of the company, suppliers and customers) will behave. Assessments are based of a set of "models of impacts" that relate the process parameters (as estimated) and the selected KPIs. For each sustainability area, a set of KPIs is defined. A set of models of impacts is defined on the basis of process parameters, as described in the following section, which values usually vary from company to company, and from sector to sector. Also this step can be executed with excel-based tools or more advanced ICT toolkit.

2.1. KPIs for sustainability assessment

For each early assessment (i.e., EEA, EHA and ECA) described in the previous section, a set of KPIs and models o impacts for their calculated is defined. Table 1 shows the selected indicators (KPIs) for each assessment, how to measure them, and the main involved parameters. Specific models of impacts combining the identified parameters are then used to evaluate the KPIs.

About EEA, selected KPIs are Energy consumption (E) and Environmental impacts vector (V), that consider the impact as done by LCA applications, but having an estimation in the early design stage for a preventive assessment. Indeed, by a proper knowledge management about workstations, operators and logistics conditions, a set of pre-defined scenarios can be defined and used for an early assessment. About EHA, KPIs refer to the assessment the quality of human actions by predicting postures, conditions and durations. In particular, a dedicated assessment method is applied based on: 1) Static Risk Score (SRS) to get a risk factor by summing the Rapid Upper Limb Assessment (RULA) impact and the Rapid Entire Body Assessment (REBA), and 2) Job Exposure Score (JES) that considers the effect of task frequency by means of OCRA checklist [22]. About ECA, KPIs consider Production Costs (CPROD) and Investment Costs (CIN) and exploit company knowledge about processes, machine operations characteristics, standard operators' actions, and hourly costs. Table 1 summarizes the KPIs and the parameters considered for each assessment.

In the following paragraphs the three above-mentioned assessment models are described in details. Each assessment is represented as a "logical function" where inputs, constrains, resources and output are indicated.

Table 1. KPIs for sustainability early assessment.

Assessment	KPIs	Unit of meas.	How to measure	Parameters
EEA	Energy consumption (*E*)	kW	$EEA = (\bar{V}_{ws} + \bar{V}_{op} + \bar{V}_l) + (\bar{E}_{ws} + \bar{E}_l)$ $\overline{E} = [kW]$ $\overline{V} = [CO_2eq;\ SO_2eq;\ NO_xeq;\ H_2O]$	$\bar{V}_{ws}$ = env. impact produced by workstations involved
				$\bar{V}_{op}$= env. impact produced by operators involved
	Environmental impact vector (*V*)	gr or lt		$\bar{V}_l$ = env. impact produced by logistic operations
				$\bar{E}_{ws}$= energy consumed by workstations involved
				$\bar{E}_l$ = energy consumed by logistic operations
EHA	Static Risk Score (*SRS*)	No.	$EHA = \overline{H}_{ws} + \overline{H}_l$ $\overline{CHKP} = [FRC;\ REC;\ RIP]$ $\overline{H} = [SRS; JES; CHKP]$	$\overline{H}_{ws}$ = human impact on workstations
				$\overline{H}_l$ = human impact during logistic operations
				$\overline{FRC\iota}$ = force exertion score
	Job Exposure Score (*JES*)	No.		$\overline{REC\iota}$ = recovery score
				$\overline{RIP\iota}$ = repetitivity score
				$\overline{CHKP\iota}$ = checklist score according to OCRA
ECA	Production cost (*C*)	euro	$ECA = \bar{C}_{ws} + \bar{C}_{rw} + \bar{C}_{op} + \bar{C}_l$ $\overline{C} = [C_{PROD}]$	$\bar{C}_{ws}$ = cost for processes on workstations
				$\bar{C}_{rw}$ = cost for raw material
				$\bar{C}_{op}$ = cost for operators
				$\bar{C}_l$ = cost for logistic operations

2.2. Models of impact for sustainability manufacturing

For each above-mentioned assessment the knowledge-based models of impact are described, where input and output are highlighted. In particular, the *EEA* needs as input parameters the product geometry and properties (e.g., shapes, material, mechanical properties), the electric furniture information, and the factory process knowledge. Furthermore, it needs machines' parameters and facility working-capacity as constraints and resources. The *EHA* requires information about product geometry, tools availability, product components positions and postures assumed by workers, and workers capabilities as input parameters. At the same time, the human resources characteristics (e.g., height, force, gender, nationality) are considered as constraints. The knowledge about the handling and moving actions (e.g., lifting, moving, turning, precision positioning) and supporting devices (e.g., screwdriver, electrical screwdrivers, use of trolleys) are considered and modeled properly to describe the operations carried out by workers during the process stages. About the *ECA*, information about the product geometry and properties as well as machines working cycle are considered as input data, data about human resources, energy consumption and fuel consumption for logistics operation are used as resources. The following sections described the models adopted for each assessment. The sustainability assessment presented below focuses on the production stage and do not considers the other lifecycle stages, but it could be easily extended also to other product lifecycle stages.

2.2.1. Early Environmental Assessment

Hereafter some examples of models of impact are provided. About manufacturing operations, two different machine states are defined: *online time*, when the workstation is currently in an active running mode, and *offline time*, when workstation is running but is not active on the production. For each state, a certain energy consumption rate is defined. The operative power specific consumption $P_{ON,k}$ and the power consumption $P_{act,k}$ can be assessed as indicated by Eq. (1) and Eq. (2) respectively:

$$P_{ON,k} = P_{n,k} * \frac{V_{t,k}}{V_{t,k}|_{max}} * \frac{s_k}{\eta_{mecc,k}} \tag{1}$$

$$P_{act,k} = \frac{[t_{ON,k} * P_{ON,k} + (t_{set} + t_{OFF})_{,k} * P_{OFF,k}]}{60} \tag{2}$$

where $t_{ON,k}$ is the interval of time where operation is effectively performed of the k workstation or machine, and depends on the specific operation and process, $P_{ON,k}$ is the electrical power absorption (in the ON state) of the specific k workstation or machine, $t_{OFF,k}$ is the interval of time where the k workstation or machine is not working, and depends on the specific operation and process, $P_{OFF,k}$ is the electrical power absorption (in the *OFF* state) of the specific k workstation or machine, and η_{mecc} is the workstation mechanical efficiency. About $t_{ON,k.}$ Eq. (3) indicates an example for milling process:

$$t_{ON} = \left(\frac{L+E}{VA} \cdot Np \cdot Nw\right) \tag{3}$$

where *L* is the depth of the operation, *E* is the extra-stroke, *VA* is the machine speed, *L* is the length to be processed, *Np* is the number of runs in deep direction (along z axis), *Nw* number of runs in length direction (along y axis). Finally for logistic operations assessment, a database can be created by coupling the company historical knowledge with environmental impact data (from LCA standards for instance) to estimate the emissions impact according to Eq. (4):

$$V_l = \zeta_{emis} * N_{trk} * D \quad (4)$$

where ζ_{emis} is the specific emission per kilometer, N_{trk} is the number and type of transport involved, and D is the distance to cover in kilometers.

2.2.2. Early Human Assessment

The *EHA* focuses on risk for the human beings involved in the different operations. According to RULA, REBA and OCRA Checklist assessment, the most human effort is calculated for each i action considering also the activity duration, frequency and rest phases. The model merges a static posture assessment, obtained by combining REBA and RULA analyses, with dynamic assessment based on OCRA Checklist. The Total Score (TS) for each activity can be calculated by Eq. (5):

$$TS_i = SRS_i + JES_i \quad (5)$$

where SRS_i is the static risk score for the i action and JES_i is the Job Exposure Score for i action that considers the effect of repetitiveness (frequency of actions). A set of pre-defined postures for workers are defined considering the most common ones: standing, seating, crunching, kneeing, tiptoed, etc. For every type of posture, effect of distances is also considered. SRS_i is assessed by a manual or an automatic application of the RULA and REBA scoring, while JES_i is defined by Eq. (6):

$$JES_i = Int[Dm_i * (SRS_i + CHKP_i) * FW_i] \quad (6)$$

where Int is a math operator that indicates that the nearest entire number must be taken into account, Dm_i is a *Duration multiplier coefficient* that considers the task frequency and the FW_i is the fraction of time during which the operator works on the workstation for the i action, and $CHKP_i$ is the OCRA Checklist score. FW_i is measured by Eq. (7) whereas $CHKP_i$ is measured by Eq. (8)

$$FW_i = tc_i / WS_i * 100 \quad (7)$$
$$CHKP_i = FRC_i + REC_i + REP_i \quad (8)$$

where tc_i is the cycle time for the i action, and WS_i is the total time on the specific workstation. FW_i takes into account that breaks are usually required to have an active anti-fatigue effect. In Eq. (8) FRC_i is the score for force exertion, REC_i is the score for the recovery (the major the score is the less recovery possibility is), and REP_i is the score for the number of actions per minute recorded.

2.2.3. Early Cost Assessment

ECA is carried out by estimating the final cost for the entire manufacturing process C_{PROD}, that considers the costs for manufacturing on workstations or machines (Cws), the costs for raw materials (Crw), the costs for human resources involved into the process (Cop) and the costs for logistics operations (Cl). They are determined by Eq. (9), Eq. (10) and Eq. (11) respectively.

$$C_{ws} = [\sum_{k=1}^{M} Q * (t_{ON} + t_{OFF} + t_{set})|_k + t_{acc}] * c_{ws} + E * c_{kWh} \quad (9)$$
$$C_{rw} = Q * c_{raw} \quad (10)$$
$$C_{op} = [\sum_{k=1}^{M} Q * (t_{ON} + t_{OFF} + t_{set})|_k + t_{acc}] * c_{hr} * w \quad (11)$$
$$C_l = \zeta_{Cons} * c_{fuel} * N_{trk} * D \quad (12)$$

where Q is the quantity of product produced, t_{acc} is the time for the equipment, t_{set} is the time needed for the setup, c_{ws} is the hourly labour cost for machines, E is the amount of electricity spent, c_{kWh} is the cost for each kWh, c_{raw} is the cost for raw material, w is the number of workers involved, c_{hr} is the hourly labor cost for human resources, ζ_{Cons} is the fuel-consumption rate [*lt/km*] according to the type of truck deployed, c_{fuel} is the fuel-cost per litre, N_{trk} is the number of trucks per type involved in the transport and D is the distance covered [km].

3. Case study

3.1. Case study description

The case study was developed in collaboration with a machine builder for the packaging sector. The proposed models of impact were applied to assess the sustainability of a high-automated filling machine that processes a flat web of packaging material to create closed packages of pre-defined shapes. The desired shape is obtained by pushing the packaging material into a forming section, made up of a set of so-called "forming rings", constituted by a sequence of tangent rollers. Usually designers create a first guess of the forming section on the basis on CAE results and their own experience. Since the machine manages liquids, both tolerances and surface roughness are very stringent and the manufacturing process is complex and difficult to assess. In the paper, the attention is paid to one of the most critical components of the system, the so-called "forming ring" (Fig.1), which has high cost and elevated human efforts for handling and assembling.

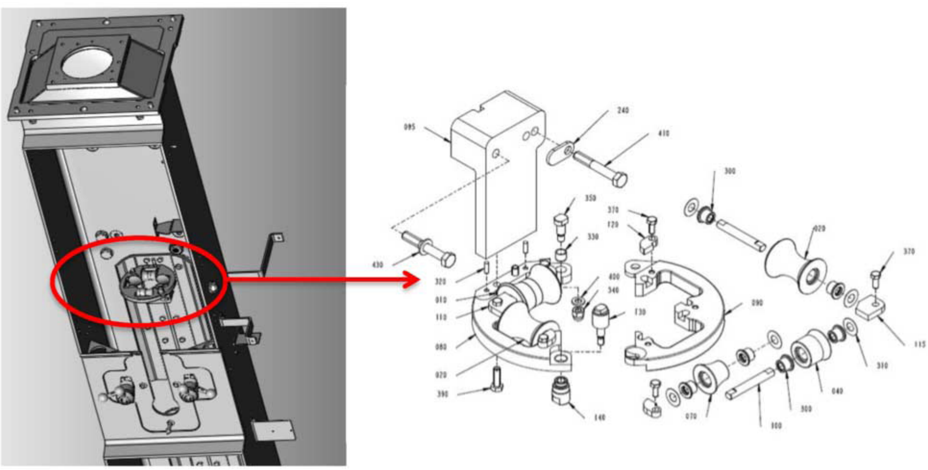


Figure 1. The forming ring (analyzed during the case study).

The models of impact were also applied to the entire machine and analyses are still in progress. Due to space limit, in the paper only results about the forming ring are reported. The main actions taken to assess the sustainability of the forming ring (hereafter "the product") were as follows:

1. Analysis of the machines adopted in the production stage: all the machines involved in the production were analyzed by collecting the necessary parameters required by the models of impacts;

2. Early definition of the production cycle: both manufacturing, assembly and logistics operations were investigated and a production cycle estimated from the analysis of the product geometry and properties as well as the assembly requirements;
3. Application of the EEA, EHA and ECA models of impact: data necessary for the three assessments were collected and the models applied.

The results about the early definition of the production cycle and the manufacturing times, supporting the following assessment, are presented in Table 2.

Table 2. Estimated production cycle and times for the forming ring (main components).

Component code	Q	n° Op.	Workstation/Machine	t_{on}	t_{off}	t_{setup}
Xxxx1	1	1.1	Bandsaw FORTE	15	0	5
		1.2	Mazak Nexus 250-500	0,3	0	5
		1.3	GravoGraph LS 900	2,4	0	0
Xxxx2	1	2.1	Mazak Nexus 250-500	3,5	0	15
		2.2	Bandsaw FORTE	0,3	0	5
		2.3	GravoGraph LS 900	2,4	0	0
Xxxx3	2	3.1	Mazak Nexus 250-500	5	0	15
		3.2	Bandsaw FORTE	0,3	0	5
		3.3	GravoGraph LS 900	2,4	0	0
Xxxx4	1	4.1	Mazak Nexus 250-500	0,96	0	10
		4.2	Bandsaw FORTE	0,79	2,42	52,4
		4.3	GravoGraph LS 900	2,4	0	0
Xxxx5	1	5.1	Mazak Nexus HCN 6800	54	0	45
		5.2	Bandsaw FORTE	5	0	1,5
		5.3	Tumbler di Maio BVC 16	3	0	0
Xxxx6	1	6.1	Mazak Nexus HCN 6800	50	0	30
		6.2	Bandsaw FORTE	5	0	1,5
		6.3	Tumbler di Maio BVC 16	2,4	0	0
Xxxx7	1	7.1	Mazak VTC 560/25	31,15	0	120
		7.2	Bandsaw FORTE	5	0	2
		7.3	Tumbler di Maio BVC 16	2,4	0	0

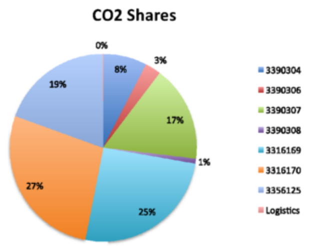
3.2. Early assessment results

The early assessment is based on EEA, EHA and ECA results. In particular, for each product component, emissions for raw materials processing and energy consumption of the involved machine are collected by existing eco-databases such as GaBi software databases [23]. As far as the energy furniture, since the company and its supply chain were located in Italy, the energy supply profile was taken directly from ENEL data [24], according to which energy is entirely generated from thermo-generation. According to the proposed models, EEA, ECA and EHA were calculated for the main components as presented in Figure 2.

Such assessments allow to anticipate product criticalities into the production process and to support the machine design in order to optimize the potential problems. For instance, from the analysis of the early assessment result, it is possible to highlight the most expensive operations (i.e. code Xxxx3) that could be optimized, and the most risky activity (i.e. lifting pieces from rack) that could be improved. It supports the design optimization according to the sustainability principles.

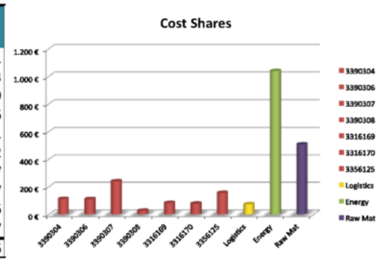
Name (o COD)	Environmental [g] CO2	NOx	SO2	[lt] H20
Xxxx1	78165,258	182,312	302,760	3,993
Xxxx2	28411,208	66,082	114,490	1,585
Xxxx3	169874,942	395,900	665,277	8,897
Xxxx4	8719,611	20,272	35,138	0,487
Xxxx5	260617,102	606,569	1039,371	14,211
Xxxx6	281765,514	655,751	1124,621	15,392
Xxxx7	199744,482	468,860	704,709	8,139

Total Consumption Calculus	kWh	[g] CO2	NOx	SO2	[lt] H20
V_raw	0,00	72558,40	174,58	157,29	0,00
V_el	1183,30	944276,96	2195,99	3806,39	52,70
V0	0,00	0,00	0,00	0,00	0,00
V_logistics	0,00	484,00	10,43	0,01	0,00
V_Q	1183,30	1017319,36	2381,00	3806,39	52,70



A)

Name (o COD)	Time (dec) [min] per piece ON	OFF	SETUP	Cost [€] Q	€
3390304	27,7	0	10	4	113,01
3390306	6,2	0	20	4	111,23
3390307	7,7	0	20	8	240,09
3390308	14,15	2,42	62,4	4	27,96
3316169	64,4	0	46,5	4	83,51
3316170	60,4	0	31,5	4	79,32
3356125	38,55	0	122	4	157,67
Logistics					73,47
Energy					1039,56
Raw Mat					508,97
Σ					886,26



B)

Repetitive Task per the kth workstation

Img_no°	No.	if Rep [R]	Name	Static Risk Score	Time [min]	Fraction of Total repetitive work [%]	Check Force	Rep	Rec
1	1	R	Lifting Pieces from rack	8	2	1,0	1	1	1
3	2	R	First positioning on Mazak	2	12	6,1	1	1	1
13	3	R	Second positioning on Mazak	5	12	6,1	0	1	1
13	4	R	Catching from Mazak	5	12	6,1	0	1	1
8	5	-	Moving on transpallet	3	12	0,0	0	0	1
7	6	R	Positioning on Bandsaw	2	14	7,1	0	1	1
7	7	R	Catching from Bandsaw	2	14	7,1	0	1	1
8	8	-	Moving on transpallet	3	12	0,0	0	0	1
18	9	R	First positioning on Mazak	6	20	10,1	0	1	1
18	10	R	Second positioning on Mazak	6	20	10,1	0	1	1
8	11	-	Moving on transpallet	3	12	0,0	0	0	1
23	12	R	Positioning on Laser Engraving	4	4	2,0	0	1	1
23	13	R	Catching from Laser Engraving	4	4	2,0	0	1	1
8	14	-	Moving on transpallet	3	12	0,0	0	0	1
22	15	R	Positioning on Tumbler	3	12	6,1	0	0	1
22	16	R	Catching from Tumbler	3	12	6,1	0	0	1
8	17	-	Moving on transpallet	3	12	0,0	0	1	1
	Σ				138	69,7			

C)

Figure 2. Results for EEA (A), ECA (B) and EHA (C) for the forming ring.

4. Conclusion

The paper proposed a set of models of impacts to evaluate the level of sustainability of manufactured parts, groups of parts or systems, to support the design of sustainable products and processes. The models have been applied to an industrial case study in the packaging sector demonstrating how he validity of the proposed method to drive the design choices by identifying the less sustainable processes in terms of costs, environmental impact and human efforts. Future works will be addressed to extend the proposed models to a wider range of manufacturing processes and to the entire lifecycle, including use and end-of-life phases.

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Exergetic Analysis Applied to Recycling Processes: A Literature Review

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Abstract. The increase of waste presents a challenge for organizations and societies pursuing sustainable development. In this context, recycling is widely recognized for being a friendly strategy to the environment and the proper approach to effectively manage waste and minimize the negative impact on the environment and the economy. However, since the available recycling technology requires both raw materials and energy, it ultimately contributes to the depletion of natural resources. Therefore, it is vital to assess the energy efficiency of recycling processes to determine their real benefit. The scientific literature suggests a series of approaches, requirements and practices, which may be, at first sight, confusing. The present study focuses on efficiency evaluation of recycling processes by means of exergetic analyses. It performs a systematic review, based on nine significant factors in recycling processes, of the relevant literature concerning the evaluation of recycling processes through the exergetic approach. The review makes two important contributions. First, it presents an approach for assessing such diverse literature by means of a single structure. In addition, it allows the identification of improvement opportunities and reveals future research opportunities.

Keywords. Energy, Exergy, Recycling, Efficiency, Sustainability.

Introduction

The waste increase is a global challenge, given that it threatens health, the environment and economies, constituting a high risk to humanity's future and society as known. Nowadays, global treaties, local legislation and specific guidelines already impose waste management. Ensuring sustainability is the only way to ensure the availability of resources necessary for the present generation without jeopardizing future ones [1]. Furthermore, it is the only way to reduce the environmental impact of human activities and to extend business continuity.

A prominent example of waste is electronic products, which at the end of their life (ELP) constitute what is known as e-waste, which is the world's fastest growing waste stream at the rate of 3-5% per year [2]. This illustrates the problem since this category generates 50 million tons every year globally due to the adoption of electronic products and technological changes [3].

Facing this problem, recycling has been adopted as the appropriate approach to manage waste, minimize environmental impact and create business opportunities [4]. To understand the complexity of recycling processes, it is important to note that most

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ELP contains a wide variety of materials, combined in sets of high complexity, making their disassembly expensive during disposal. Instead, to recover materials, the recyclers apply shredding and separation processes. During shredding, ELP is broken into particles to release materials which are subsequently submitted to separation processes [5].

At the same time, the efficiency of current technology is only able to separate and recover materials at the minimum levels set by regulation or technical requirements by adding a series of processes of shredding, separation and cleaning. However, these are industrial processes and so they consume materials and energy and generate waste. This may make the recycling process inefficient from an environmental or energetic perspectives [6, 7]. Assuming that recycling is a strategy to make better use of resources, its efficiency becomes a key point without which paradoxically there is no way to ensure thorough recycling and the best use of resources at sustainable levels.

As a result of investigation, an exergy concept is found, which has been adopted in the analysis of the energy efficiency of devices or industrial processes in several industries. Based on the Second Law of Thermodynamics (SLT), it can be revealed how much of a given quantity of energy is actually being transformed into work, and how much is destroyed and so how much can be expressed in the same energy unit. About efficiencies, energy is based on conservations of the First Law of Thermodynamics, while the exergy efficiency differs by using the SLT to evaluate quantitatively and qualitatively all the exergy conversion. Its use allows us to differentiate losses to the environment of internal irreversibility, reflecting the performance based on the maximum limit imposed by SLT [8]. There are energy conversions with high exergy destruction, while an energy analysis indicates a high efficient energy conversion, for example, the case of the electric heater [9].

This is why many researchers advocate the use of exergy where truths taken for granted are challenged. For instance, manufacturing processes considered as modern from an energy point of view are less efficient than traditional processes [10]. In addition, some legislations motivated by environmental purposes impose high recovery rates that hurt conservation principles of SLT [11]. Thus, exergy stands out, being an able tool in revealing unknown inefficiencies. Besides, exergy has direct relationships on two of the three pillars of the sustainable triple bottom line. From an environmental point of view, it is an indicator of energy and material depletion, from an economic point of view, being exergy, the useful energy part has economic value [12].

This work aims to present an evaluation framework that relates articles published on recycling and their efficiency by exergy approach, thereby promoting exergy practices and identifying research opportunities. It is organized as follows. In section 1, the concepts are presented and the most relevant works are briefly described; in section 2 the research method is described; in section 3, the results are shown; in section 4, result analyses and a discussion about the future, trends and opportunities are presented; finally, in section 5, the final considerations are presented.

1. Fundamental Concepts

Being exergy, a principle that can be deployed in many applications of different impacts, it is necessary to review concepts and highlight non-trivial relations between exergy and the pillars of sustainability and, finally, about the recycling. Below, concepts are described to justify the study, throwing some light on the results later presented.

1.1. Brief history of exergy

Energy is composed of an available portion able to produce useful work, also called exergy, and a portion of energy, which is not available, known as anergy [13]. The need to determine the available energy or the quantity of mechanical work that can be extracted from it has long been recognized [14-17]. However, it is important to note that exergy, unlike energy, is not subject to the law of conservation: the irreversibility that may appear in the real process destroys, at least, a part of exergy. In fact, many situations in which people use the term energy is, in fact, exergy [9]. It is so important that some authors have focused their contribution on the resolution of this conflict, clearly defining the difference between the two concepts as shown in Table 1 [18].

Table 1. Energy & Exergy definition, source: [18].

Energy	Exergy
Dependent only on field parameters or energy flows and does not depend on environment	Dependent both on the parameters of material or energy flows and environmental parameters
Movement or capacity to produce movement	Work or capacity to produce work
Always kept in a process by which it cannot be destroyed or produced	Always kept in a reversible process, but is always consumed in an irreversible process
In equilibrium with the reference environment, its value is not zero	In equilibrium with the reference environment, its value is equal to zero

The four following literature constitute an adequate definition of exergy concept [19], thus establishing a foundation: [14] the relationship between heat and work, which later resulted in the formulation of the second law of thermodynamics; [15] the first expression of the general relationship for the work; [13] the first suggestion of "exergy". Therefore, a general definition was proposed in the form in which it is still widely used, especially in energy conversion applications [20]: Exergy is the portion of energy that is fully convertible into all other forms of energy.

Despite being widely used, due to context, this definition may be misleading [21]. This is because it implies that the system of "total energy" is composed of two parts, a "convertible" (exergy) and another non-convertible (anergy). However, there are examples of systems with a negative anergy (solid below T0, gases in certain age of T <T0 and P <p0, etc.) that limits this definition. Table 2 shows "exergy" evolution term [13].

Table 2. Evolution of the term Exergy, source: [22].

Year	Author	Designation in the language of origin	Translation to English
1824	Carnot	*Puissance motrice du feu*	Drive Capacity of fire
1824	Carnot	*Puissance motrice du feu*	Drive Capacity of fire
1872	Thomson (Kelvin)	*Motivity*	-
1873	Gibbs	*The available energy of the body and medium*	-
1881	Gouy	*Energy utilizables*	Useful energy
1898	Stodola	*Freie technische energie*	Free technical energy
1925	Debaufre	*Available Energy*	Available power
1935	Bošnjaković	*Technische Arbeitsfähigkeit*	Working Readiness
1944	Thring	*Virtue of energy*	Energy virtue
1953	Schmidt	*Technische maximale arbeit*	Maximum technical work
1955	Gibert	*Énergie non dégradée*	Energy not degraded
1956	Grigull	*Ekthalpie*	Enthalpie
1956	Rant	*Exergie*	-

By way of definition, exergy [15] is described as the theoretical maximum useful work obtained if a system is put into the thermodynamic equilibrium with the environment which the system interacts with. In the meantime, the debate on the basis of efficiency was on until the 1980s, resulting in two definitions proposed and in use today [23]:

"Exergy is the amount of work obtained when any matter is carried to a state of thermodynamic equilibrium with the common components of the natural environment, by means of a reversible process, involving single interaction with the same components mentioned of environment."

“Exergy is the axis of work or the electrical power required to produce a material in a specified state by means of common materials in the environment of reversible form, being the heat exchanged solely with the environment at temperature T0."

Since there are many forms and materials in which energy flows are present in nature, there are corresponding forms of exergy. The commonly used ones are in Table 3 [21].

Table 3. Content of the specific exergy of different energy flows, source: [21].

Energy specifies	**Energy specifies**	**Specific energy consumption**	**Source**	**Notes**
Kinetics	$0.5V^2$	$0.5V^2$	/	J/kg; followed by definition
Potential	$g\Delta z$	$g\Delta z$	/	J/kg; followed by definition
Heat	q	$q\left(1-\frac{T_0}{T_q}\right)$	/	J/kg; followed by definition
Mechanical	w	w	/	J/kg; followed by definition
Electrical power	$It\Delta V$	$It\Delta V$	/	J; followed by definition
Chemistry, pure substance	Δg_G	$\mu - \mu_0 R T_0 ln\left(\frac{c}{c_0}\right)$	[24]	$\mu - \mu_0 = \Delta g_G = g_G - g_{G.0}$
Radiation	I	$\sigma\left(T^4 - \frac{4T^3T_0}{3} + \frac{T_0^4}{3}\right)$	[25]	W/m^2; for radiation black body

1.2. Environmental aspects in exergy

Many authors suggest that to mitigate the environmental impact of energy resource use, best results are obtained when exergy is used, because it is a useful concept in improving efficiency [12]. Once exergy is the confluence of energy, the environment and sustainable development, as shown in Figure 1, the basis for this treatment is the interdisciplinary character of exergy and its relationship with each of these disciplines.

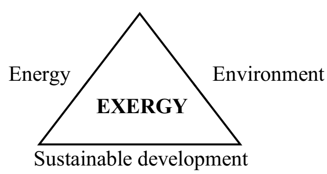

Figure 1. Diagram Interdisciplinary triangle covered by the field of exergy analysis, source: [12].

Waste heat emissions to the environment should also be a concern and, if neglected, can cause the increase of environmental temperature and thus the thermal pollution, which can compromise, among others, the marine life and the ecological balance of lakes and rivers [26], [27] and [28]. It is suggested that the exergy analysis of the natural processes that occur on Earth could form a basis for an ecologically correct planning, as it would indicate the disturbance caused by changes in a large scale [29]. This points to three relations between exergy and environmental impact for processes as shown in Figure 2 where exponential improvements are shown in terms of exergy efficiency [30].

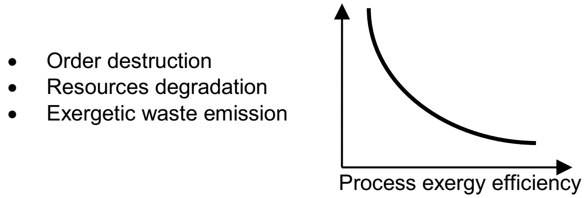

Figure 2. Qualitative relationship between the exergy efficiency and environmental impact, source: [12].

1.3. Economic aspects in exergy

When energy loses quality because exergy is being destroyed. Being exergy, the useful part of energy, it has economic value and must be managed [12]. In other words, the exergy destruction implies economic waste translated into monetary value, thus, it is directly related to operation costs in recycling and the economic sustainability as a business.

With environmental orientation, Life Cycle Assessment (LCA) became a popular technique in the past two decades to analyse environmental problems related to production, use, disposal or recycling of ELP [31]. However, from the economic point of view it was suggested that traditional LCA cycle "from cradle to grave", should be modified to "from grave to grave". This was to calculate the exergy cost of replacing degraded materials during the whole life cycle in exergy terms as cost expression [32]. Furthermore, the value of the total cost measured in exergy units is called exergo-ecological cost, noting that the higher the exergo-ecological cost for a product, process or service, the more unsustainable it will be, also from the economic point of view.

In a case study, exergy analysis revealed that the usage of exergy was only 4%, i.e., a high index of destruction of exergy and so economic waste [33]. In addition, it identified the main points of waste with an improved energy consumption 30% lower. Thus, it is possible to identify also the economic benefits in exergy analysis.

About economic interactions between exergy and recycling, every time we recycle, we are avoiding a deficit associated with the huge cost necessary to replace minerals. Even more, to reach the same exergy concentration they had originally [32]. From this point of view, once more, it is possible to relate exergy as an indicator of economic efficiency in recycling processes.

2. Methodological procedures

The adopted method is a systematic review that in terms of evaluation proposes that the review of the literature is preceded by some criteria that will judge and select the literature [34]. The revision panel composed of experts in the field shall develop such criteria. However, a change was made since the specific literature is dispersed and the specialists are not available. Thus, the panel of experts was replaced by the performance criteria of recycling processes found in the literature of a high impact journal (JCR 3.220), which are hierarchized and described in its adopted level 3, as in Table 4 [35].

The research databases were Science Direct, Springer, Web of Science and Scopus from June to September 2015. The criteria used were envisioned to refine the research on relevant criteria for the performance of the recycling having in common the exergy approach.

Table 4. Evaluation of performance of recycling, source: [35].

Criteria Level 2	Criteria Level 3	Description Level 3
Environmental impact (C1)	(C11) Reduction of landfill	Measures the amount of reduction of waste into landfill due to the adoption of a specific recycling program.
	(C12) Regulatory Compliance	Focuses on the level of engagement with the compliance and environmental regulations of a specific recycling program.
Social Responsibility (C2)	(C21) Health and safety in the workplace	The number of requests for indemnification of the worker in the organization.
	(C22) Public acceptability	The attitude and general public perception of the recycling program
	(C23) Corporate Reputation	The satisfaction level of interested parties on the recycling program
Economic Sustainability (C3)	(C31) Direct Benefit	Profitability by the effective implementation of the recycling program.
	(C32) Indirect Benefit	Refers to potential entrepreneur's opportunities / markets operated due to the implementation of recycling programs.
Technical feasibility (C4)	(C41) Ability to separate the materials of e-waste	The ability to separate materials including toxic materials, plastics, chlorinated ferrous and non-ferrous metals.
	(C42) e-waste recovery	The amount of waste retrievable from the recycling process.

The research was performed by keywords and their combinations, having included 'Boolean operators' more common as 'AND', 'OR' and 'NO' [36]. For the keywords, their synonyms and neologies were also considered, without restrictions as to the date or language. In order to scrutinize the articles, it was analysed if their scientific contribution referred to exergy in the context of recycling, relevance, bibliographic references, and its relationship with other jobs in the same research line.

From the selection, all articles were tabulated in chronological order by article`s date of acceptance or in the absence of this, by the year of publication. From this distribution, the assessments were executed based on pre-established criteria [35]. For weighting, a scale was adopted where: 3 means a strong relationship; 1 a tenuous relationship; and 0 no relationship. Then, for each elected article, a quantitative and descriptive analysis was made, relating the relevant content to the theme, application predominance and trends for future research.

3. Results

From this point, the results and the main contributions of each paper are presented in a descriptive and chronological way.

With economic purposes, this is one of the first studies correlating SLT, exergy, sustainability and recycling [37]. Its propositions are as follows. (1) Human well-being is a function of economic production. (2) Production is inherently of material consumption. (3) Material processing requires available power (i.e. exergy); it converts low entropy materials (i.e. metal ores) into high entropy materials (i.e. waste). (4) The stock of high-quality materials (low entropy) on Earth is finite. (5) Material recycling for materials of high entropy into low entropy requires an exogenous flow of energy of low entropy (i.e. exergy). (6) Materials can never be recycled with 100% efficiency because there are always entropic losses.

The relationship between exergy and material is reinforced when it is affirmed that exergy can analyse industrial processes, the materials' cumulative exergy consumption and resources conversion [38]. This is also the first literature to highlight the benefits between exergy and recycling [32] . In an exergo-economic study, is was stated that to entirely calculate the product life cycle it is necessary to calculate the "exergy cost of raw materials replacement". On materials, it is emphasized that the dilution process is widely identified in recycling processes [32]. Dilution is one of the most irreversible processes, being easy to mix and expensive to separate. This is due to the fact that the exergy destroyed in a mixing process is small while the exergy to separate it is huge with current technology. Only biological mechanisms can do so at reasonable cost [39].

There were controversies due to the argument that total recycling is impossible as a consequence of SLT [37]. A study has shown that in respect of certain conditions, such limitations do not exist. However, it is accepted that even the most efficient recycling process will generate high entropy waste. Therefore, given exergy postulates, it is possible to treat the "trashcan" as a source and any residue, retrospectively, returns to the "trashcan" [40].

One of the greatest recycling challenges is the mixed particles separation. By using gases, was demonstrated that this issue could be better addressed by "mixture entropy" calculation. In addition, the analysis shows that the requirement of consumption for separation by *mol* of a substance increases to low dilution. It means that it is better to run recycling systems with substances on the highest possible concentration [41].

Exergy approach is proposed as an indicator suggesting that all product wastes may be taxed by the amount of exergy released into the environment since it is related to the environmental impact [42]. Also, as an indicator, it has proposed and exemplified the exergy approach for the assessment of alternative techniques for recycling systems [43].

Based on the importance and difficulty of materials separation [44], a reasoned decision model, in limitations of exergy that assesses the compatibility between different alloys and the separation need as well as acceptable levels of contamination, was proposed in the metallurgy context. Still about mixing in metallurgy [45] was proposed in the metallurgy context, a reasoned decision model in limitations of exergy that assesses the compatibility between different alloys and the separation need, as well as acceptable levels of contamination. Still about mixing in metallurgy [45], a method that combines exergy losses and a consequent need for dilution as indicators of quality during the recovery and recycling of metals was proposed. With a similar approach, exergy was proposed as an efficiency indicator of product recycling processes [46], [11]. It is important to say that it was identified that regulation may harm, in many cases, principles on the SLT [11]. It also identified important contributions while the evolution of efficiency is historically described in exergy context [47].

With a future vision, exergy was used to create over 51 nature minerals, an inventory of exergy resources available on the planet highlighting that iron (63%), aluminium (24%) and copper (6%) together are responsible for 93% of the planet's exergy degradation by metals [48]. Based on Hubbert's prediction curves, it outlines an "exergy regressive clock", pointing to the depletion of these resources in nature, thus emphasizing the recycling importance [49]. Following this shortage scenario, the need for recycling, energy efficiency and the use of materials was reinforced; it was also stated that we should be prepared for a future in which we have to deal with impure materials, furthermore defending what seems to be a tendency in design strategies to facilitate the recycling [50].

To overcome obstacles in recycling implementation, emphasis was given to non-fuel minerals, in which recycling costs may be greater than mining and refining. It was done by pointing weaknesses and strengths and of many approaches and the latter, proposing that exergy costs provide a more realistic measure for energy efficiency [51]. In a literature review focused at sustainability, and in this context to recycling, exergy approach was confirmed as a method to guide energy efficiency as well as waste reduction [52]. The next moment, combining the LCA method with exergy was proposed as a method to assess the environmental impact of a hybrid-electric vehicle, examining its decomposition into subsystems and doing an analysis of exergy destroyed [53]. In order to control costs, the method of "Exergy Accounting" was proposed, assigning exergy values equivalent to the capital cost. The method combines classic exergy analysis with the well-known aspects of sustainability [54].

Once the tabulated data was quantitatively analysed, most of the literature was identified focusing on efforts to use exergy approach in recycling with technical or economic goals. Meanwhile, in the exergy recycling context, environmental aspects are still little explored and the social aspects almost disregarded.

4. Projects and Opportunities

Despite the magnitude of the exergy concept, when applied to recycling, the literature focuses on economic and technical aspects, while recycling focuses on efficiency. However, this addresses environmental and social aspects in a superficial way, thus characterizing a research opportunity.

The review shows that more than a half of studies concentrate their efforts on metallurgy. It seems natural, since a few alloys are responsible for 93% of exergy metals depletion; however, it allows for enquiring if a greater effort to replace metals should be conducted, thereby revealing a research opportunity.

It also reveals a great concern with contamination, given the difficulty in separate materials and the efficiency due to purity, still suggesting more efforts to create or improve methods that mitigate mixing. Here, three trends are noted: (1) Methods for Design for Remanufacturing or Disassemble. (2) Studies suggesting that to reduce separation would not separate compatible materials. Some metallurgy methods could be adapted to other materials that could replace them (e.g. polymers). (3) Discussions about the limits of recycling and recovery of raw material and the counterexamples found in nature would suggest that biomimetic could drive another research in recycling efficiency.

Relating to the methodology of exergy calculation applied to the context of recycling, major concept differences are not revealed. The variety of methods indicates that to create a new one does not appear to be necessary. However, grouping, organizing and detailing them could be useful to stimulate exergy approach in industry. Meanwhile, the combined approach of LCA with the exergy, then called ELCA (Exergy Life Cycle Assessment) begins to be highlighted as a technic that may remediate the identified gap of low use of exergy approach focused to environmental sustainability in recycling practices.

5. Final considerations

This work reaches its objectives when it gathers a universe of articles found within the context of recycling and exergy, through a chronological framework that identifies the strengths of each article and extracts their main contributions. Furthermore, it provides a database on the subject, creates hypotheses and reveals research opportunities. It is now possible to understand how the scientific progress in this area occurred, without having to repeat the work of scrutinizing databases. Despite the literature relating specifically to recycling and exergy still being modest, there is an identifiable, although slight, increase in publications.

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A Procedure to Validate Industrial Symbiosis Indicators Combining Conceptual and Empirical Validation Methods

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Abstract. Industrial symbiosis is the exchange of by-products, energy and water between industries, centered on a collective approach, and in order to achieve competitive advantages. It is central to the concept of Eco-Industrial Park (EIP) and requires continuous monitoring of the professionals involved. Performance indicators for the measurement and monitoring of industrial symbiosis have been proposed and identified in the literature, however there is no consolidate indicator that is widely used in practice. These indicators require validation in order to evaluate and choose which options are able to measure the industrial symbiosis. There are two types of indicators validation, the conceptual validation and the empirical validation. This study investigates the integration of the conceptual validation and the empirical validation in the evaluation of the industrial symbiosis indicators. It is proposed the combined use of an indicator validation methodology based on expert judgment, the 3S Methodology, and a simulation technique, the Agent-Based Modeling (ABM). The proposed procedure aims to validate any indicator of industrial symbiosis, providing specific criteria to the evaluation.

Keywords. Industrial Symbiosis, Performance Indicator, Indicator Validation, Agent-Based Modeling.

Introduction

Industrial Symbiosis is characterized by a better use of by-products and waste. It is an essential part for the formation of Eco-Industrial Parks (EIP) [1, 2].

EIP is a concept of industrial arrangement created in the early 90's, where companies seek sustainable development through mutual cooperation [3, 4]. According to Lowe [4] and Veiga and Magrini [5], the concept has spread to several countries through applied projects and publications.

The industrial symbiosis monitoring and measurement in this type of park are imperative. Performance indicators have been proposed for this purpose. However, as noted by Rigby *et al*. [6], while is employed great interest in developing new performance indicators, little effort is intended to their validation. This is also observed with regard to the indicators for industrial symbiosis measurement, because none of the

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identified articles [7, 8, 9, 10, 11, 12, 13, 14] deals with the validation, but with their proposition or use.

Performance indicator validation is important because, according to Bockstaller and Girardin [15], it aims to verify if an indicator is scientifically designed, if it provides relevant information and if it is useful to its users. The validation provides greater accuracy to the indicator.

The indicator validation process can be dived into two stages: the conceptual validation and the empirical validation [15]. The first is based on the indicator data, information and description, where the validation through expert judgment is always possible [15].

Empirical validation is the indicator evaluation through visual or statistical procedures [15]. The indicator application is required, which can be accomplished through a real case or with simulated data [15].

The article proposes a procedure that incorporates aspects of both validation stages, comprising a validation methodology based on the expert judgment and a simulation through Agent-Based Modeling (ABM) technique.

1. EIP and Industrial Symbiosis

The Eco-Industrial Park concept was created in 1992 by the Indigo Development institute [4]:

> (...) a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize by only optimizing its individual performance [3].

According to Chertow and Ehrenfeld [16], an EIP should be considered as a dynamic system, where the park is a complex and adaptive environment, being influenced by external factors (*e.g.* market conditions) and internal factors (*e.g.* business strategies), and the system has the self-organizing ability. The industrial symbiosis is one of the ways by which an EIP can self-organize and achieve an equilibrium state [16].

The industrial symbiosis concept is presented by Chertow [17] as a metaphor where the industrial ecosystem mimics a natural ecosystem. It is responsible for the cooperation between different companies through the exchange of material, energy, water and by-products, achieving competitive advantages [17].

According to Chertow *et al.* [18], there are three types of symbiotic transactions: (i) utilities and infrastructure sharing; (ii) use of common services; (iii) by-product exchanges, where a company uses waste from another company as raw material.

Chertow [17] points out that geographical proximity is a key factor for the industrial symbiosis development, because it is through this proximity that the synergic cooperation possibilities arise. Finally, Felicio *et al.* [14] comment that the perfect symbiosis is impossible to reach, it can always be increased.

2. Indicators Validation

As already defined in the Introduction, the purpose of a performance indicator validation is to verify if the indicator is scientifically designed, if it provides relevant information and if it is useful to its users [15].

2.1. 3S Methodology

The 3S Methodology, by Cloquell-Ballester *et al.* [19], is an indicator conceptual validation methodology that aims to ensure quality, reliability and objectivity for indicators. It is based on expert judgment.

Criteria in the form of questions are used in the evaluation procedure. These criteria are separated into three classes (Conceptual coherence; Operational coherence; Utility) [19]. These criteria are presented in Table 1.

Table 1. 3S Methodology Evaluation Criteria.

Questionnaire to evaluate the indicators to be validated
Conceptual coherence
1.The definition of the indicator and the concepts that comprise it up is suitable
2.There is a biunivocal correspondence between the indicator and the factor to be quantified
3.The interpretation and meaning of the indicator are suitable
Operational coherence
1.The mathematical formulation of the indicator is suitable with regard to the concept which is to be quantified
2.The data used to establish the indicator and its units are suitable
3.The proposed measurement procedures to obtain the indicator are suitable, allowing for its reproduction and comparison
4.The indicator accuracy is suitable to quantify the factor and it is sensitive to changes in the latter
Utility
1.The indicator reliability is suitable
2.The reliability of the source of data which the indicator is made up of is suitable
3.The accessibility to the data and the applicability of the indicator are suitable
4.The information provided by the indicator may be catalogued as reliable
5.The cost of the information offered by the indicator can be considered acceptable

Source. Cloquell-Ballester *et al.* [19], p. 87.

The criteria classes are designed to satisfy the three conditions proposed by Bockstaller and Girardin [15]. The conceptual coherence aims to verify if the indicator is scientifically designed; while the operational coherence verifies whether the indicators provides relevant information; and the utility verifies whether the indicator is useful to users.

Experts are responsible for answering the questions, assigning scores 1 to 5 (Likert Scale), totally disagreeing or totally agreeing respectively [19]. An Indicator Report must be prepared so that the evaluators can access more easily the indicator's information [19].

The final score of each criterion is the average of evaluators' scores for that criterion. The criteria's scores are aggregated to form the classes' scores, which are aggregated to obtain the final score for the indicator. According to Cloquell-Ballester *et al*. [19], the indicator can be classified according to the Table 2.

Table 2. Indicator Classification.

Final sore	**Classification**
More than 4.5	Validated
Between 3.5 and 4.5	A brief review is required
Between 2.5 and 3.5	A thorough review is required
Less than 2.5	Unacceptable. Redefine

Source. Adapted from Cloquell-Ballester *et al*. [19].

The 3S Methodology consists of three stages, differentiated by the type of evaluator [19]: (i) Self-validation – Executed by the working team that developed the indicator; (ii) Scientific validation – Conducted through independent expert judgment; (iii) Social validation – Includes public participation.

2.2. Simulation in the Indicators Validation

According to Bockstaller and Girardin [15], a way to proceed with the empirical validation of an indicator is evaluating its behavior through simulation.

Among the various techniques employed to produce a simulation, Agent-Based Modeling emerges as the main option for an EIP. It has, as one of its main advantages, the no need to represent the system completely, but only its individual agents, so it is possible to understand the dynamics that results from the interaction of agents with each other and with the environment. This makes the modeling process simpler.

Furthermore, there are studies that used the ABM to represent an EIP. The model proposed by Bichraoui *et al*. [20] focuses on understand the cooperation and learning conditions that permeate the park. While the model proposed by Romero and Ruiz [21] has the aim to evaluate the influence of the symbiotic relationships in the global operation of the EIP.

3. Proposal of a procedure to validate industrial symbiosis indicators combining simulation and the 3S Methodology

The proposal of the new procedure to validate industrial symbiosis indicators is divided into three phases. At first, the 3S Methodology is adapted with regard to the evaluation criteria in order to be applied in industrial symbiosis indicators. Second, a simulation model of an EIP, that considers its symbiotic relationships, is proposed. Finally the integration between the two previous phases is described, resulting in the new validation procedure of industrial symbiosis indicators.

3.1. Adapting 3S Methodology

There are no specific criteria for the evaluation of industrial symbiosis indicators in the literature. Furthermore, the criteria proposed by Cloquell-Ballester *et al.* [19] were considered superficial, too much embracing, and even repetitive.

The first adaptation of 3S Methodology identified as necessary is the adaptation of the criteria proposed by Cloquell-Ballester *et al.* [19]. Table 3 presents the new criteria, specifics for the application on industrial symbiosis indicators.

Table 3. Evaluation criteria adapted for the application on industrial symbiosis indicators.

Questionnaire to evaluate the indicators of industrial symbiosis to be validated
Conceptual coherence
1. The indicator measures the exchange of water, energy and by-products between companies in a eco-industrial park eco industrial, correct representing the industrial symbiosis
2. The indicator classifies the different by-products in accordance with appropriate criteria
3. The indicator considers amounts of by-product reused. In a direct way*
4. The indicator considers amounts of by-product discarded
Operational coherence
1. The mathematical formulation is suitable for measuring industrial symbiosis, taking into account the aspects that must be quantified
2. The data needed to calculate the indicator are relevant, while there are no data that are relevant and are not considered
3. The measurement procedures for obtaining the data are adequate, allowing their reproduction and comparison
4. The indicator is able to indicate trends
5. The numerical result has no limit, meaning that the industrial symbiosis can always be improved
6. The indicator allows comparison with other parks
Utility
1. The indicator calculation and its procedures do not require excessive effort
2. Data sources are reliable
3. Data sources are easy to access
4. The indicator final result has meaning
5. The costs required for data collection and indicator application are acceptable

*The indicator is able to record directly the by-products that are reused, rather than, for example, quantify them by the decrease in the use of virgin raw material.

The criteria classes was not changed, because they are in accordance with the presented by Bockstaller and Girardin [15] in the indicators validation theory. The criteria adaptations were based on the EIP and industrial symbiosis theory, presented in Section 1. In addition, the studies containing the symbiosis indicators [7, 8, 9, 10, 11, 12, 13, 14] were also studied. However, due to space limitation, details of these indicators are not presented.

Another adjustment made in 3S Methodology concerns the three stages differentiated by the type of evaluator. The 3S Methodology authors, Bockstaller and Girardin [19], argue that, with this differentiation, the indicator credibility increases with the passage through the three stages. We do not disagree with the authors, however, we believe that this restricts the use of the 3S Methodology to the indicator creators. And the intention is that the procedure proposed here be used both by the indicator creator and by who wish to use the indicator or by who just wish to validate it. The proposed adaptation is to extinguish this differentiation of evaluators.

3.2. EIP Simulation through ABM

There is no study that uses an agent-based model in the representation of an EIP that aims to apply performance indicators. So we developed a simulation model of an EIP through ABM technique, using the NetLogo [22] platform, which has the purpose of representing the interactions between the companies that compose the EIP with regard to by-products flow, and allows the calculation of industrial symbiosis indicators.

In summary, the model allows:

- Entrance and exit of companies in the EIP;
- Creation of by-products exchange links between companies;
- Variation in the amounts of by-products traded between companies;
- Variation in the amounts of by-products generate by each company;
- Dispatch of by-products not used to the landfill.

The model behavior depends on input data provided by the user, which can calibrate the model in different scenarios. To consider the calculation of the indicators it is necessary to modify the source code of the model in order to include the calculation of the desired indicators. This requires additional effort, however, because it was used the ABM technique, this effort is not excessive. Furthermore, the most complex part of the source code is already written. However, due to space limitations, the model will not be described in detail.

3.3. Integrated Validation Procedure

3S Methodology, according to Section 2.1, proposes that an Indicator Record should be created, so the evaluators have access more easily to the information about the indicator to be validated. The integration between conceptual and empirical validations happens at this point. We propose that simulations complement the Indicator Report. More than theoretical information about the indicator and its construction, the report will also contain simulations of the indicator behavior, demonstrating its evolution in different scenarios.

The one interested in validating the indicator must establish the preconditions to guide the construction of scenarios. These conditions can be grounded by aspects that differentiate the indicator or by a set of typical events in an EIP. The one responsible for designing the Indicator Report is the right person to perform the simulations through the model and, eventually, by inserting the indicator calculation in the source code.

4. Result

The result is the validation process of industrial symbiosis indicators, named “Integrated Validation Procedure for Industrial Symbiosis Indicators”. Figure 1 presents the process of this new procedure.

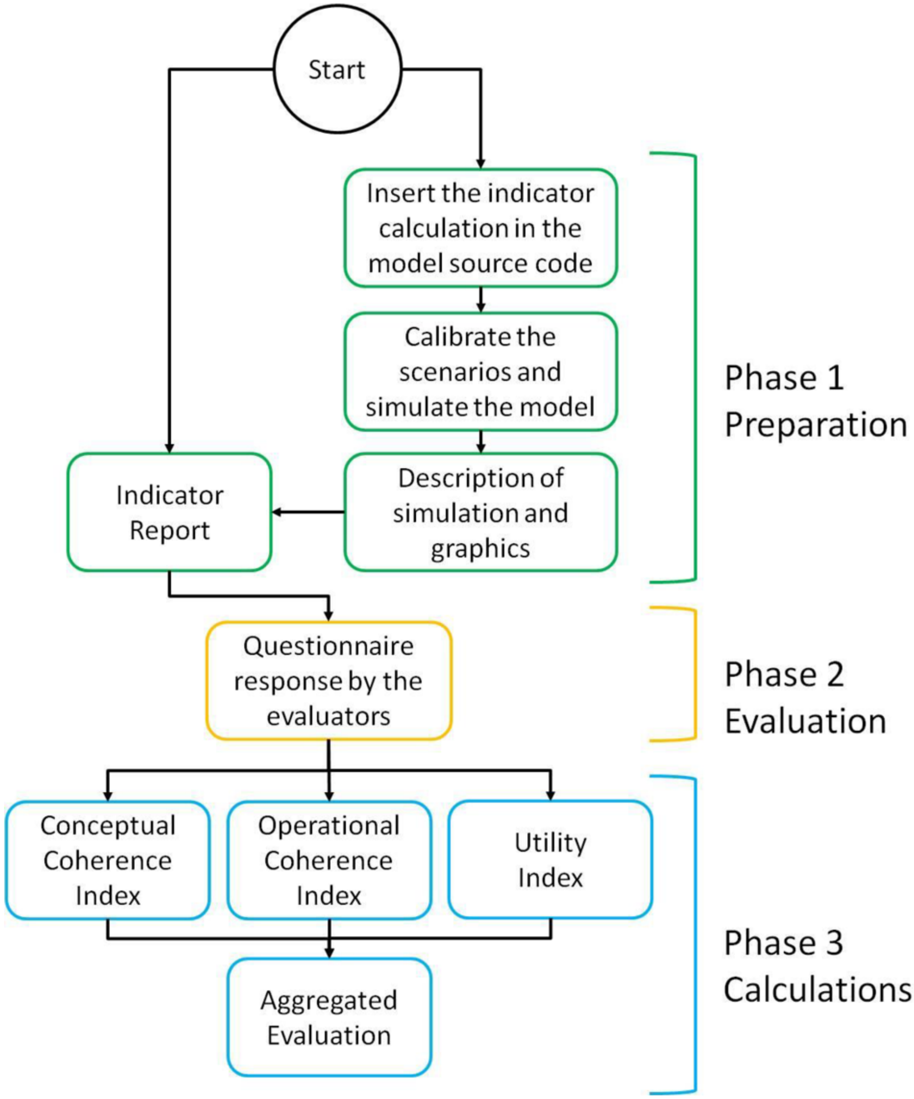


Figure 1. Integrated Validation Procedure for Industrial Symbiosis Indicators.

The process is divided into three phases: (i) Preparation; (ii) Evaluation; (iii) Calculations. Although the Evaluation phase is the "core", because it is in this phase that the experts assign scores to the criteria, the Preparation phase is the most laborious and has great importance, because it is in this phase the documents that will guide the whole evaluation are created. Any errors or omissions may jeopardize the entire process.

The Evaluation phase comprises only the questionnaire response by the evaluators, the questionnaire is presented in Table 3. The last phase, Calculation, is where the evaluators' responses are compiled and the scores of each of the three indices (Conceptual coherence; Operational coherence; Utility) and the Aggregated Evaluation are obtained. For the final decision, whether the indicator is validated, we followed the recommendation of Cloquell-Ballester *et al.* [19] presented in Table 2.

With regard to Indicator Report, we took the suggestion of minimum content, by Cloquell-Ballester *et al.* [19], and added the description of the simulations. Table 4 shows what these information are.

Table 4. Minimum content of Indicator Report.

Guide for indicator report	
1. Indicator	Name of the proposed indicator
2. Aspect	2.1. Name of the environmental or social aspect (system component) to be quantified through the indicator
	2.2. Description: description of the environmental or social characteristic that represents the aspect
3. Description	3.1. Conceptual definition: definition of the indicator and of the concepts and characteristics that it is made up of
	3.2. Description of data and units: description of the data and units used to quantify the environmental aspect
	3.3. Operational definition: definition of the mathematical expression used to quantify the environmental aspect
	3.4. Measuring method: details about sampling and/or measuring procedures followed by the indicator to be obtained. Possibility to reproduce and compare the measurement
4. Justification	4.1. Interpretation/meaning: Description of its interpretation and meaning through explanation of its operation
	4.2. Accuracy: explanation of the indicator's accuracy and sensitivity to changes in the factor and security of both information and data
	4.3. Relevancy: explanation of the indicator's relevancy to represent the characteristic that is to be quantified (aspect)
5. Sources	Availability of data sources. Name of the documents and/or files where the data comes from
6. Simulations	6.1. Scenarios description: description of the scenarios calibrated to simulate the indicator
	6.2. Simulations: graphics and numerical results of the indicator during the simulated period
	6.3. Behavior: description of the indicator behavior in each scenario

Source. Adapted from Cloquell-Ballester *et al.* [19].

Figure 2 presents an example on how the part that explains the simulations in the Indicator Report should be provided to the evaluators. We choose to present only this part because this is the innovative part of the report. It should be created as many scenarios as it deems necessary to represent the behavior of the indicator that is being validated.

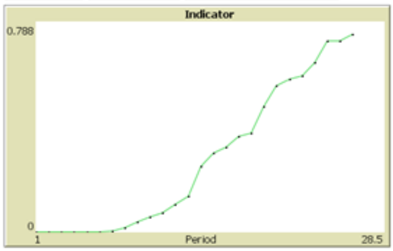
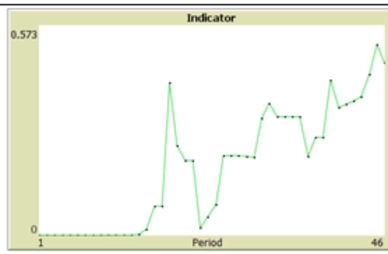
	6.1. Scenario description	6.2. Simulation	6.3. Behavior
Scenario 1	The scenario describes an optimal situation for the development of the industrial symbiosis, where the companies in the EIP are willingness to exchange by-products...		In the simulation was observed increase at every period, the indicators behavior is explained because...
⋮	⋮	⋮	⋮
Scenario n	Description of the scenario.		Description of the indicator behavior.

Figure 2. The Simulation part in the Indicator Report.

5. Conclusion

The procedure proposed combines aspects of both conceptual and empirical validations to validate any indicators of industrial symbiosis. The gain in insert the simulation in a validation through the expert judgment is the provision of more information of different kinds to the evaluator, which will have more knowledge on the indicator.

The adaptation of the evaluation criteria for the specific application in industrial symbiosis indicators is another positive aspect of the procedure. Due to the possibility to simulate more than one indicator at the same time, this procedure also allows the evaluators to compare the indicators during the process of assigning scores to the evaluation criteria.

The need of great effort in the Preparation phase, particularly with regard to the simulation, is considered the main difficulty in applying the procedure.

This paper provides only the proposal of this new procedure, the practical application has not yet been held. As a next step, we will apply the procedure, verifying its applicability and possibly improving and proposing a final version.

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Influence of Organizational Characteristics in the Sustainability Strategy

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Abstract. The corporate sustainability is about incorporating sustainability into corporate strategy, and it will be decisive for the business development. It also emphasizes the search for a balance in the economic, social and environmental perspectives. This strategic adoption changes the management and organizational characteristics, but the question is if the opposite can happen. In this sense tried to relate some characteristics in a sample of companies, with the sustainability strategy. From the data collected was used a multinomial logistic regression analysis. There was the relationship between five companies characteristics (independent variables) with 15 aspects of corporate strategy and sustainability (independent variables). Thus, the conclusion that has sustainability in the strategic agenda has an important influence in the sustainability strategy for these companies and other features can also exercise, even if on a less scale.

Keywords. Sustainability, Sustainability strategy, Multinomial logistic regression

Introduction

Sustainability is a topic that has been discussed in various segments. Forward it to business organizations, this strategy can be considered as a assignment or a prospect. For Porter [1], the strategy is the searching for a sustainable position by of a specific and related set of operations that generate synergy and are difficult to imitate. Thus, strategy means deciding actions that can leverage a company to the future or take it to failure. Strategies must be sensitive to environmental issues and encouraging organizations to abandon damaging practices to the environment and society, going to engage other social and environmental.

The changes and modifications in the business paradigm occur with regularly, brought by the social interactions and the environment changes and necessary resources for survival [2]. These changes from agreements between organizations that are now adding to sustainability commitment. Table 1 present the sustainability landmarks cited by [3-8].

The United Nations (UN), through Agenda 21, aims to ensure the evolution of human activities concerning policy and strategies decisions of the government and

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companies. Thus, authorities from different areas of global interest have been using conservation alternatives and sustainable exploration [5][9]. Loette [10] mentions Henderson [2] in the Sustainability Compendium:

"*A new awareness can lead to the creation of a new, more equitable and sustainable world. We are talking of nothing less than reinventing ourselves, reframing our perceptions, reshaping our beliefs and behavior, composting our knowledge, restructuring our institutions and recycling our societies.*"

In the view of Feldmann [5], the profit is the most important, regardless of the use of resources for the environment and to provide the people's well-being. Use resources only in order to ensure business survival is not considered therefore immoral. For Elkington [11] in the "*Triple Botton Line*" natural resources must be preserved to have a prospers and fair society.

Table 1. History evolution of sustainability.

Year	History event
1968	Rome Club foundation to discuss issues related to environment, international policies and economic of world personalities.
1972	UN Conference on Environment and Development with the participation of 113 countries in Stockholm - Sweden.
1972	Rome Club Report - The Limits to Growth by Donella H. Meadows, warning of the effects of pollution and natural resources ends.
1975	Establishing priorities for the control of industrial pollution in the Second National Development Plan - NDP 1975-1979.
1979	Berne Convention - habitat protection.
1980	Lester Brown, founder of Worldwatch Institute, introduced the concept of sustainable community as it meets their own needs without reducing the opportunities of future generations.
	Use of the term "deep ecology" that identifies the man as part of the holistic and unified environmental complex system.
	Geneva Convention - Air pollution
1983	The UN establishing the World Commission on Environment and Development. Appears the term "sustainable development" by the Brundtland Report "Our Common Future", which supports to ensure the standard of living and maintain the technological development without the planet's natural resources ends.
	Helsinki protocol - Air quality.
1987	Montreal Protocol - substance that destroy the ozone layer.
1991	The International Chamber of Commerce (ICC) adopted the "Environmental Guidelines for World Industry" by setting environmental management commitments to be assumed by companies. IBrazil was created the Brazilian Foundation for Sustainable Development.
1992	Agenda 21 represents a result of consensus accomplished by the international signatory document community of 179 countries on environmental issues in their various socio-economic and cultural aspects.
1997	Founded and was representative of the World Business Council for Sustainable Development (WBCSD), the Brazilian Business Council for Sustainable Development (CEBDS) has the mission to integrate the principles and sustainable development practices. CEBDS part of a global network of over 50 National Councils that are working to spread a new way to do business around the world.
	Kyoto Protocol in Japan presenting a proposal to reduce the emission of greenhouse gases. Until 2009, 187 countries had acceded to the Protocol.

Year	History event
1999	John Elkington defines Triple Bottom Line (3BL) establishing the components of sustainable development: economic prosperity, social justice and environmental protection in business operations.
2002	Rio + 10 event in Johannesburg, this United Nations Conference, discussing and evaluating the results achieved after a decade of Agenda 21 and to formulate new proposals - "Business Action For Sustainable Development".
2009	15th Climate Conference (COP15) by the United Nations in Copenhagen, bringing together 25 Heads of State.
2012	Aiming to ensure that the Rio + 20 observe the pillars of sustainable development, the Brazilian government created within the National Organizing Committee, a Sustainability Coordination. Their function was to analyze and propose actions to reduce, mitigate or compensate for environmental and social impacts generated by the Conference.

Agenda 21 is a sustainability plan for the twenty-first century and uses three essential dimensions to which all organizations should attention: economic, environmental and social. The economic pillar is the generation of wealth, the environmental conservation of nature and the social participation of the whole society sharing rights and responsibilities in the construction and maintaining system balance.

When it comes to corporate sustainability, the strategy company's formation will be crucial for the business development. Thus, Mintzberg [12] determines that the organization strategy is represented by a specific standard to a set of decisions, namely a behavioral company consistency over time.

Since the sustainable development of an organization covers three basic principles - social equality, economic growth and environmental balance - a wide concept of sustainability strategy should also include these three perspectives. In this meaning, Coral [13] states that, as economic growth is present in the competitiveness, sustainability strategy of a company depending on its competitiveness, its relationship with the environment and social responsibility.

The research question of this study is: the studied of companies characteristics influence the sustainability strategy? At this way, the objective is to ensure that the companies' characteristics influence the sustainability strategy.

1. Methodology

This study used the results obtained by Machado et al. [14]. And that survey had 16 initial questions about the companies characteristics and of the respondent, and 93 other of sustainability, witch were divided in 6 groups. The first dealing with corporate strategy and sustainability and others 5 subsequent groups were about processes and practices aimed at topics as product design, evaluation life cycle, purchasing, corporate social responsibility, among others.

The scale used to answer 93 questions reflect maturity levels also addressed by [14]. The level of implementation may be 0 to 5, and these: non-existent (0), the initial (1), managed or repeated (2), defined (3), quantitatively managed (4), and optimized (5). This scale is not valid for a multi-criteria analysis because the length between the levels are not uniform. It was decided to use a multinomial logistic regression.

Table 2. Description of the dependent variables.

Variables	Questions of Corporate strategy and sustainability block
DV 1	The sustainability strategy is directed to fulfillment/compliance of all regulations and/or standards applied to business.
DV 2	The company directs efforts to stay ahead of emerging regulations, especially those that can create competitive advantage.
DV 3	There are formal processes of research to identify and analyze sustainability trends related to business.
DV 4	The sustainability strategy is formalized and supported by top management.
DV 5	There is a specific area to management sustainability (e.g. board or sustainability management).
DV 6	The company develops business cases (sustainability business cases) that clearly demonstrate the economic results of sustainable or to prove the value proposition to address sustainability practices.
DV 7	Operations or practices applied to the chain-of-value of the company are adjusted or changed as a result of the results of practices and/or sustainability strategy.
DV 8	The business model of the company was changed due to the results of practices and/or sustainability strategy.
DV 9	There operational KPI's (Key Performance Indicators) related to sustainability.
DV 10	There are personal KPI's related to sustainability.
DV 11	The company is linked to the regulatory bodies and others responsible for policy formulation as a reliable source of information, enabled to influence and perhaps compile new regulations and policies.
DV 12	The company seeks to identify significant issues of sustainability (environmental, social and economic) that directly impact the business (called material sustainability/ materiality).
DV 13	The company has risk management strategy related to climate change, disasters and risks.
DV 14	The guidelines and sustainability goals are defined and shared by the top management.
DV 15	Senior management plays a strong role in the company's sustainability efforts.

Source: by authors (adapted from [14]).

The questionnaire was sent to companies adhered to the Global Pact or another volunteer commitment, participants ISE/BOVESPA, that publishing GRI reports, using ETHOS indicators and are ISO 9001, ISO 14001 and OHSAS 18001, as well as professionals selected according with the managerial position and scope of companies, 100 bigger companies and more than 150 employees according to the FIEP (Federation of Industries of Parana State) industrial catalog and participating in graduate programs with functional link with manufacturing companies. The database used for this study was 64 questionnaires.

The statistical method was the multinomial logistic regression, which is used to variables model of nominal results in the log probabilities are modeled as a linear combination of predictor variables [15]. The software used for analysis was IBM SPSS Statistics 2.1. Only the Corporate Strategy and Sustainability block was chose to study because of its scope. And the analysis was performed for each dependent variable (DV), i.e., each issue group. These can be checked in Table 2.

The independent variables (IV) correspond to the first questions of the questionnaire, those relating the company and respondent. To choose which would be studied, the 15 multinomial logistic regressions with all the issues, and selected the 5 most significant. Table 3 presents the independent variables selected.

Table 3. Description of the independent variables.

Variables	Questions related to the companies
IV 1	Sustainability is inserted in strategic agenda of business management?
IV 2	The company has quality management system?
IV 3	The company has energy management system?
IV 4	The company has Corporate Governance?
IV 5	The company is a signatory of some type of voluntary commitment for sustainable development?

Source: by authors (adapted from [14]).

They were then held 15 multinomial logistic regressions - one for each dependent variable - with the five independent variables.

2. Results and discussion

First it should be focus on data obtained from multinomial analysis can not be generalized. This is because to the use of secondary data obtained from a questionnaire used in Machado et al. [14] with a sample of only 64 companies, i.e., the sample makes it impossible to determine comprehensively results in total by just having been based on specific criteria and the number of responses represent a percentage similar to the definition of the sample criteria.

However, for this multinomial analysis were established 15 dependent variables and correlated to 5 independent variables. The significance values of these multinomial regressions are presented in Table 4.

It was found that the independent variable "sustainability is embedded in the organization strategic agenda (IV1)" presented less significance than 0.005 in relation to most of the dependent variables, i.e., the fact of having entered the sustainability on the agenda it has strategic relations of influence in compliance with all regulations and/or sustainability standards applied to business (DV1); in efforts to stay ahead of emerging regulations, especially that can create competitive advantages (DV2); in contributing to formalization of a sustainability strategy supported by high management (DV4); the creation of a specific area to sustainability management (DV5); operations or practices applied to the company's value chain are adjusted or changed as a result of practices and/or sustainability strategy (DV7); change the business model because the results of practices and/or sustainability strategy (DV8); operational KPI's (Key Performance Indicators) related to sustainability (DV9); personal KPI's related to sustainability (DV10); the search for identifying 3BL significant issues and that directly business impact (DV12); the risk of strategy management company related to climate change, disasters and risks (DV13); the guidelines and sustainability goals are defined and shared by the high management (DV14); high management plays a strong role in efforts for sustainability company (DV15).

Table 4. Significance of multinomial logistic regression.

	IV 1	*IV 2*	*IVI 3*	*IV 4*	*IV 5*
DV 1	0*	0.011	0.232	0.006	0.021
DV 2	0*	0.022	0.343	0.391	0.291
DV 3	0.008	0.014	0.81	0.325	0.32
DV 4	0*	0.357	0.128	0.378	0.026
DV 5	0*	0.211	0.689	0.741	0.015
DV 6	0.023	0.087	0.561	0.091	0.022
DV 7	0*	0.003*	0.128	0.067	0.046
DV 8	0.002*	0.045	0.471	0.144	0.12
DV 9	0.002*	0.018	0.021	0.159	0.024
DV 10	0.002*	0.079	0.039	0.615	0.005*
DV 11	0.01	0.011	0.147	0.031	0.032
DV 12	0.001*	0.002*	0.551	0.086	0.144
DV 13	0.002*	0.024	0.054	0.565	0.03
DV 14	0*	0.003*	0.855	0.079	0.228
DV 15	0*	0.081	0.327	0.151	0.05

* Significance < 0,005. Source: by authors.

To analyzing the found results, related to business strategy, Grant [16] which deals with strategy as a way to make a link between the organization and the external environment, highlighting three key: its objectives, its resources and the organizational structure resulting from the organization internal relationship. In the external environment, there are economic, social, political and technological factors that influence the company performance and decisions. Thus, the competition that describe the external environment in which the operations companies was analyzed with the interactive process of competitors through its strategic initiatives and its reactions to other companies initiatives.

In the same context, Grant [16] states that one of the ways the organizations succeed in maintaining a competitive advantage is through the strategic differentiation, which must go beyond changes to the product, including all aspects of the relationship between consumers and the companies. So, the suggestion is to gain competitive advantage through differentiation, should be analyzed the company and the product from two perspectives: the demand and the organization. Analyzing to the consumer's perspective means determining with the costumer which product characteristics have the potential to create value and how much is disposed to pay for them. Regarding the perspective of the organization, the needs to develop its functions in order to promote their unique in the market, is based on the characteristics of the product and technology in complementary services, experience of employees, productivity, quality, among other organizational aspects.

The independent variable (IV1) is not significant for the existence of formal research process to identify and analyze sustainability trends related to business (DV3); for the development of business cases that clearly demonstrate the economic results of sustainable practices or to prove the value proposition to approach sustainability

(DV6); connection to regulators and other policy makers formulations as a reliable source of information, enabled to influence and/or may create new regulations and policies (DV11).

The independent variable "the company has Quality Management System (IV 2)" is significant when related to the dependent variables "operations or practices applied to the company's value chain are adjusted or changed as a result of the results of practices and/or strategy sustainability (DV7)", "the company seeks to identify significant issues of sustainability (environmental, social and economic) that directly impact the business (called material sustainability/materiality) (DV12)" and "guidelines and sustainability goals defined and shared by high management (DV 14)." This significance indicates that owning a quality management system contributes to the adoption of the preceding practices.

A trend that can be highlighted is the growth of organizations that drive and even certify companies as the adherence to sustainable actions, like the Global Pact and the Global Reporting Initiative (GRI). In them are published principles and indicators that organizations can use as a basis to measure and report their economic, environmental and social performance. The goal is that these sustainability reports may become routine and that are comparable [17].

The independent variables "The company has Energy Management System? (IV3) " and "The company has Corporate Governance? (IV4)" have no relation to any of the dependent variables.

The independent variable "The company is a signatory of some of voluntary commitment for sustainable development? (IV5)" presented significance only on the dependent variable "There KPI's related to personal sustainability (DV10)", or influence this.

In the Gallopin [18] perspective, the indicators used to measure the sustainability level can be considered the progress of the evaluation components. For Bellen [19], there are numerous measurement problems, the indicators are part of the process of understanding the relationship and the field of development. By definition, sustainable development indicators are imperfect instruments and not universally applicable and it is necessary to know the characteristics of the different systems.

The results presented in this analysis allow some conclusions that are valid only for the sample of Machado et al. [14] from that multinomial analysis.

Note that the inserted sustainability in strategy means that the organization management is important as first change the guidelines and objectives, it ends up causing significant changes in the business model depending on the 3BL approach levels that were applied (IV1 relations with DV12-15) (DV2's relations with DV14). However, this is at a strategic level within these organizations confirmed by [11, 20-24].

Strategic decisions down in the organizations hierarchy and modify operations, creating or modifying the practices and therefore the indicators (IV1 relations with DV4, DV7-10). A specific area to management sustainability at an early time, it is essential, but it can be taken up later to achieve a maturity in this area (ratio of IV1 with DV5), [20, 24]. Achieving sustainable operating results depend on the emphasis on the strategic level.

Quality Management can contribute at this stage, if there is a quality management at a high level of maturity in greater ease of understanding of sustainable goals for adaptation and creation of focused sustainability practices and indicators (DV2 relations with to DV7), [25].

These results are the strategic decisions answers, that well-designed and managed, tend to influence or keep forward the generation of regulations and/or sustainable standards, to influence the supply chain in which it operates and creating competitive advantages over competitors also being feedback to the strategic level (IV1 relations with DV1-3) (DV2's relations with DV12), [26, 27]. And ultimately create sustainable value, according to Ueda [28]; Lubin and Esty [29]; BM&F BOVESPA [30]; Porter and Kramer [20].

What was described in the three preceding paragraphs are a brief description of various frameworks of sustainability, including: Accountability - AA1000; Social Accontability - AS 8000; Global Reporting Initiative - GRI; Environmental Management Standards - ISO 14000; International Guidelines for Social Responsibility - SR ISO 26000; Commission on Sustainable Development; Tripple Bottom Line - 3BL; Dow Jones Sustainability Index - DJSI; ETHOS; Corporate Sustainability Index BOVESPA - ISE BOVESPA.

In a study conducted by Petrobras Sustainability Center [31], which conducted a survey similar to Machado et al. [14], it is observed that the companies studied have an adequate perception of the sustainability concept, and that 90% of respondents believe that this should be a business priority, generating environmental, social and economic outcomes. However, many of these companies do not apply the sustainability concepts in practice. In addition, 77% of respondents are sure of reasons for sustainability are to contributes tangibly to the results of companies.

Many of the addressed issues in this study were also analyzed by Petrobras Sustainability Center [31] with different approaches. These are: the specific sector responsible for sustainability; sustainability as part of the planning process; the existence of KPI's; the reporting of sustainability results as a strategy; among others.

As for the strategic issue Mirvis and Googins [32] argue that companies which are in the sustainability low stages only consider its benefits and market vision to society, that is, seek only for their own benefit, and not the whole. According to the study [31], 77% of respondents demand that sustainability is part of the business strategy, and 63% discuss the issue within the company. The sustainability assist in regulatory pressure management is also stated by 77% of companies. Moreover, 92% of respondents believe that sustainability enhances your reputation, and 87% have the perception that sustainability is important to your customers.

Fact that the sustainability inserted in the strategy not be significant for the existence of formal research process to identify and analyze sustainability trends related to the business, is not significant and may be due to the group of companies comprising the sample being sustainability pioneer in their segments. This may be an explanation for informality in the search process, and can consider the hypothesis that practice could considered new attempts will occur until it reaches the right practice.

In a clear demonstration of the results of sustainable practices or to prove the value proposition to sustainability approach, it is not significant and may be due to an excess since the gains in sustainable value sufficient or are above what was planned. Being a sustainability model implemented continuous improvement form, it will certainly be revised and reconfigured without the need for a specific approach.

For binding to the regulatory bodies and others responsible for formulation policy as a reliable source of information, enabled to influence and/or may compile new regulations and policies, is not significant, and can contemplate the negative influences of various stakeholders, the different trade relations in a globalized world, among others, but can also be the maturity difference between the organizations in the sample and the regulatory and other.

The theme of sustainability, to be formally entered in the strategic agenda of these organizations have a key role in the development and sharing of guidelines and objectives in which these organizations will follow, which is observed before its significance for most of the dependent variables. This shows that means of the collected and analyzed data, there is a very important relationship for organizations to insert the sustainability theme in the business agenda.

Some variables showed no influence; however, these are also important sources of analysis because for this sample the factors Energy Management and Governance do not influence the dependent variables. Thus, the fact that these companies have or not these processes will not influence on organization sustainability strategy.

This work results can conduct the organizations that wish insert sustainability in their strategic agenda and do not know how to do it. Starting by characteristics, competences and practices comprehended for this study variables, more organizations can conciliate in balance the environmental, social and economic aspects, to reduce the negative impacts and generate benefits to the business and society as a whole.

3. Conclusion

The results presented answer the research question, showing statistically that some of the features - sustainability being inserted in the strategic agenda of business management, the company has quality management system and a signatory of some kind of voluntary commitment for sustainable development - the companies studied influenced in their sustainability strategies.

The results, analysis and conclusions is valid only for the sample, i.e., for the respondent organizations questionnaire Machado et al. [14]. Thus, the comparison of this with other studies of the same subject is almost impossible.

Although limited, this study shows is important as it exposes the possibility of causality between certain characteristics and the company's strategy, encouraging the study of this subject in more depth and with a larger number of companies. Furthermore, a unusual method of statistical analysis was used.

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Measure Additive Manufacturing for Sustainable Manufacturing

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Abstract. Additive manufacturing technologies are still brand new in industrial production. Although It has widely been used in prototypes development, either low or very low scale production are also able to incorporate such technologies nowadays. The application of additive manufacturing in large scale has been presented as a paradigm to be overcome. Nevertheless, the application of these technologies worldwide might affect production systems dynamics in addition to organizations structures. At the same way, applying additive manufacturing technologies in medium and large scale might also create either novel businesses models or improve marketing segments that were underestimated. For that reason, the main goal of this paper is to investigate the metrics applied in additive manufacturing to identify the main advantages and disadvantages of these scenarios in a systematic study which correlate the economic, social and environmental key points which provide current manufacturing companies to identify the suitability of each additive manufacturing technology in accordance with its business goals. Therefore, the sustainable metrics for additive manufacturing processes will prove that it is really a sustainable manufacturing. Moreover, these results were results of others preliminary studies which might open a new discussion topic among manufacturing companies.

Keywords. Additive manufacturing, Metrics, Measure, Sustainable manufacturing

Introduction

In general way, additive manufacturing (AM) is defined as a manufacturing process which is used to produce three-dimensional objects by adding layers of material based on a three-dimensional computer model. Among the several definitions of this process, we can highlight 3:

"3-D printing employs an additive manufacturing process whereby products are built on a layer-by- layer basis, through a series of cross-sectional slices" [1].

"Process of joining materials to make objects from 3D model data, usually layer upon layer, opposed to subtractive manufacturing methodologies, such as traditional machining" [2].

"AM systems build parts by depositing, fusing, curing, or laminating consecutive layers of material" [3].

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Depending on process, material and technology, AM can be used in different sectors segments, such as architecture, aviation, aerospace, art, automobiles, consumer products, education, electronics, energy, entertainment, healthcare, nanotechnology, repair, tools and visualization [4]. Moreover, the suitable AM process for a product can be selected according to the application, the material, the mechanical resistance and other considerations [5, 6].

AM has been presented by many people as a clean technology and also a sustainable manufacturing. The main argument might be based on the rational and efficient use of raw materials, low waste production, reuse of raw materials and waste, reducing additional productive resources, a flexible production and demand, among others.

In spite of the potential of the AM, there is not measurement enough that supports the definition ofthose processes as sustainable manufacturing. For this, it is still necessary to have a proper definition of sustainable production in its broadest aspect, and verify whether the AM fits within all requirements. Thus, the main objective of this work is to check whether AM can be considered a sustainable manufacturing by analyzing the economic, environmental and social indicators applied to this technology.

1. Literature Review

1.1. Additive Manufacturing

Usually, AM main processes are: a) fused deposition modeling (FDM), b) stereolithograpy (SLA), c) inkjet printing (IJP), d) laminated object manufacturing (LOM), e) selective laser sintering (SLS), f) three dimensional printing (3DP), as show in Figure 1.

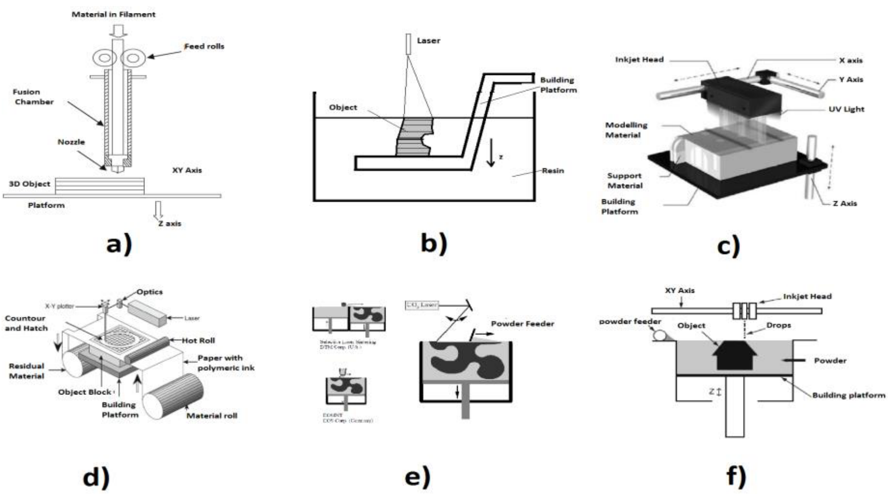

Figure 1. AM technologies processes schematic illustration (adapted from [5, 6]).

In Figure 1, the six AM processes are illustrated and the manufacturing method is based on the object layer-by-layer, in all cases. Generaly, the FDM process to create the object through the thermoplastic material deposit on a platform while a liquid resin is photopolymerizable by laser SL processes. In IJP processes, an inkjet head turns drops of liquid resin, and a UV lamp solidifying these drops. For LOM, the main material is paper, plastic or metal laminate form. The object is formed by cutting and adhesive bonding and cutting processes. In a SLS process, the powdered material is melted by laser or siterizad, to form object, 3DP process as glue powder inkjet binding [5-7].

1.2. Sustainable Manufacturing

Sustainable manufacturing involves the contribution of the productive sector companies [8], this means that the entire production system in the broadest aspect, including the supply chain, should not polluters; energy and natural resources conservatives; economically viable; safe and not evil with workers, communities and consumers; socially and creatively rewarding with all workers [9-11].

Some regulations and standards has been proposed for regulating and ensure the sustainable manufacturing are some of them: *Accountability* – AA 1000; *Social Accontability* – AS 8000; *Global Reporting Initiative* – GRI; *Environmental Management Standards* – ISSO 14000; *International Guidelines for Social Responsability* – SR ISO 26000 [11, 12]; *Commission on Sustainable Development* [13]; *Tripple Bottom Line* – TBL or 3BL [14, 15]; *Dow Jones Sustainability Index* – DJSI [16]; ETHOS [17]; *Corporate Sustainable Index* BOVESPA – ISE BOVESPA [18].

It is observed that there are several measuring proposals for sustainable manufacturing, the approaches are different, and it is impossible to consider that only one is correct and it be universal. But they note that the indicators have a greater approach to corporate sustainability. And, this does not prevent them from being applied to measuring sustainability production system of a company.

For a manufacturing measurement application must comply with broad aspects of economic, environmental and social, by means of specific sub-indicators manufacturing. Thus, data will be collected on the production system that will confirm the sustainability of this particular manufacturing.

As in AM several technologies the verification can occur in two ways. The first can check the production indicators in the economic, environmental and social aspects of each technology in AM. The other is the same check and list them in order to find equivalencies that can determine the equality of these indicators in all aspects. Thus, this correspondence would assert a compliance between all indicators for the different AM technologies.

1.3. Indicators of sustainable production

Beyond the concept of sustainable development from UNCED [19] bring up the concept of sustainable production. Before that many industries are realizing advantages in sustainable and measuring it in full sustainability aspects. Sustainable production as LCSP [20]: “the creation of goods and services using processes and systems that are: non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for workers, communities, and consumers; and, socially and creatively rewarding for all working people“.

The companies that had sustainable production goals, have sustainable production pratices, and need to measure sustainable production progress. For the measurement are used indicators, exclusively numerical, that provide information about the economic, environmental and social production.

Most of the indicators are already tracked by the companies, but it still necessary to understand sustainable production with economic, environmental and social emphasises in addition to the aspects which companies production practices, according Veleva et al. [9]. The same authors have stated that it is more operational, since it highlights six main aspects of sustainable production [21]:

- energy and material use (resources);
- natural environment (sinks);
- social justice and community development;
- economic performance;
- workers, and;
- products.

1.4. Indicators for AM

Bell and Morse [22] believe that the indicators can be defined for a particular interest and not according to what it really necessary to be measured. They define the indicators that will be used to focus in aspects that can bring advantages and hide those which can jeopardize company's image and interests, even if knowledge about these aspects are important by others.

The indicators to measure AM in the range of sustainability are few extensive, inconsistent and uncorrelated. The metrics should be more focused on performance and sustainable manufacturing, which actually comply with demonstrating the reality.

The metrics found in the literature are more on economic indicators to try to enable this technology for products, manufacturing and supply chain. There are many articles comparing AM technologies with traditional manufacturing even though a inappropriate indicators use is applied. Nevertheless, economic indicators are clearly the highlighted advantage againstthose technologies disadvantages. Thus, it can be said that AM tecnologies have not been possible to be categorized as sustainable manufacturing yet. That confirms what Bell and Morse [22] tell us about indicators.

Environmental indicators reflect more reality, measuring up the waste, consumption of raw materials, energy consumption, among others. In this case, they are more specific and demonstrate the green benefits and benefits to the corporate image. Already social indicators are not addressed in a manufacturing vision, which certainly involve the health and safety of those involved directly AM technology. Only report benefits as the development of customized medical products for more specific care of some special needs, such as prostheses developed with AM technology.

Another aspect disregarded in a simple point view isthat these indicators are not correlated. And it certainly affects each other.

2. Methodology

The theoretical development and results comes from conceptual discussions of literature from a literature review in order to respond the goals. Searches in AM references databases following topics: additive manufacturing, sustainability and indicators.

The content raised perceive the importance of this new technology in the global industrial landscape, the possibilities in product development, which refer to all existing AM processes. Addition, came the need to check each alignment or differentiation of AM processes indicators existing, noting the peculiarities of each.

Should be noted that there are diverse AM technologies, and the approach of the indicators aim to respond to AM's sustainable manufacturing, i.e., is not been measuring the technology or its advances, but the application of these technologies in production systems directly, even though at this moment it is only a conjecture.

As a result of these initial considerations studies AM indicators for sustainable production in its broadest aspect (economic, environmental and social) were incipient. Therefore, another direction was adopted. Passed to work with sustainable production indicators applied AM technologies to respond the research question.

The work of Veleva and Ellenbecker [21] shows indicators for the sustainable production and a classification for maturity levels on a framework. It is expected that verification of AM technologies indicators is sufficient, to the end, be able to state that AM is a sustainable manufacturing.

3. Development

We can see in Table 1, that literature about AM and sustainable manufacturing were found, and it have not answered the current research question yet. It was really motivating to find in the literature only indication that AM is a sustainable manufacturing. And, at this time, Veleva and Ellenbecker [21] sustainable production indicators revealed the solution to this research.

Sustainable Production indicators are common in any type of production system, giving the adjustments in the metrics. The aspects of sustainable production indicators can be applied without adjustment for energy and materials use; economic performance; justice and social community development; workers; and products.

Even without the need for adjustment is still needed for some indicators more detail. The materials used and energy used indicators have to be in full measure and per unit of product. The costs associated with environmental, health and safety (EHS) compliance reduce the economic performance, i.e., are costs through pollution prevention and cleaner production means real savings and Increased profits, reduce product/service price, increased shareholder value, wages, worker benefits, investment in R&D, fines, liabilities, worker compensation, fees for waste treatment and disposal, tradable permits, remediation costs, cost/depreciation of control equipment, labor costs [21].

The rate of customer complaints and returns indicator is about the number of complaints returns per product sale. And, the rate of employees'suggested improvements in quality, social and EHS performance need to collect employee suggested improvements about job satisfaction and morale, providing rewards to the participants [21].

In natural environment aspects, specifically the waste generated indicator, which can be emissions, solid and liquid waste, should be measured after the recycling process. Global warming potential (GWP) and potential acidification indicators had changed the metrics for emissions of gases applied AM technologies. And, the indicator for persistent, bioaccumulative and toxic (PBT) chemicals used has not been changed.

Table 1. AM for sustainable manufacturing from literature.

Author/Year	**AM Technology**	**Short paper considerations**
Mani, Lyons and Gupta/2014 [23]	General AM Tech	AM advantages.
Nation Institute of Standards and Technology – NIST/2013 [24]	Metal-Based	Metal-Based advantages only on reduce the waste in manufacturing, reducing energy used in production of raw materials and in the processing steps.
Le Bourhis et al./2013 [25]	General AM Tech	Presented a new methodology for environmental impact assessment in the AM machine.
Huang et al./2013 [26]	General AM Tech	Societal impact of AM from a technical perspective.
Bertling et al./2013 [27]	SLS	Presented sustainability environmental aspects for AM and the FabLab as a paradigm shift in consumer-producer-relationship.
Isanaka and Liou/2012 [28]	General AM Tech	Overview for sustainable quality control, time and predictive maintenance of the AM equipment to the roles of AM technologies.
Scott et al./2012 [29]	General AM Tech	Overview of technical challenges to measuring the environmental impacts and sustainability of AM processes.
Nopparat and Kianian/2012 [30]	General AM Tech	Investigated AM technology through the result-oriented Product-Service Systems (PSS) approach. And AM has higher efficiency in raw material usage, has higher energy consumption too.
Brackett et al./2011 [31]	General AM Tech	Overview of topology optimization methods for AM are key drivers toward realizing energy efficiency and reducing environmental footprint.
Baumers et al./ 2011 [32]	Polymeric Laser sintering	Overview of energy consumption and reporting specific energy consumption during the production of dedicated test parts.
Diegel et al./2010 [33]	FDM	Overview of design perspective: design quality and sustainability.
Hao et al./2010 [34]	FDM (Food application)	Overview of sustainable production efficiency improvement by optimizing AM process parameters and reduction of energy consumption.
Sreenivasan et al./2010 [35]	SLS	Overview of reduce energy consumption in SLS of non-polymeric materials.
Hiller and Lipson/2009 [36]	FDM	Overview of flexible fabrication processes in which 3D multi-material objects are fully recyclable and re-usable.
Morrow et al./2007 [37]	SLS, 3DP, LENS, DLF, DMD	Case studies about Direct Metal Deposition (DMD)-based manufacturing can reduced environmental emissions and energy consumption.

Table 2. Indicators of sustainable production and adapted for AM technologies.

Aspect for SP	Indicator	Metric	Indicator adapted for AM	Metric
Energy and material use	Fresh water consumption	Liters	Fresh water consumption	Liters
	Materials used	kg	Materials used	kg
	Energy used	kWh	Energy used	kWh
Natural environment (including human health)	Waste generated before recycling	kg	Waste generated before recycling	kg
	Global warming potential (GWP) (CO_2 or equivalent)	Tons	Global warming potential (GWP)	m^3
	Acidification potential (SO_2 or equivalent)	Tons	Acidification potential	m^3
	PBT chemicals used	kg	PBT chemicals used	kg
Economic performance	Costs associated with EHS compliance	$	Costs associated with EHS compliance	$
	Rate of customer complaints and returns	No.	Rate of customer complaints and returns	No.
	Organization's openness to stakeholder review and participation in decision-making process (scale 1–5).	No. (1-5)	Organization's openness to stakeholder review and participation in decision-making process (scale 1–5).	No. (1-5)
Community development and social justice	Community spending and charitable contributions as percent of revenues	%	Community spending and charitable contributions as percent of revenues	%
	Number of employees per unit of product or dollar sales	No./$	Number of employees per unit of product or dollar sales	No./$
	Number of community-company partnerships	No.	Number of community-company partnerships	No.
Workers	Lost workday injury and illness case rate (LWDII)	Rate	Lost workday injury and illness case rate (LWDII)	Rate
	Rate of employees' suggested improvements in quality, social and EHS performance	No.	Rate of employees' suggested improvements in quality, social and EHS performance	No.
	Turnover rate or average length of service of employees	Rate (years)	Turnover rate or average length of service of employees	Rate (years)
	Average number of hours of employee training per year	Hours	Average number of hours of employee training per year	Hours
	Percent of workers, who report complete job satisfaction	%	Percent of workers, who report complete job satisfaction	%
Products	Percent of products designed for disassembly, reuse or recycling.	%	Percent of products designed for disassembly, reuse or recycling.	%
	Percent of biodegradable packaging.	%	Percent of biodegradable packaging.	%
	Percent of products with take-back policies in place	%	Percent of products with take-back policies in place	%

Source: Indicators of sustainable production (adapted from [21])

4. Results

Now, after the sustainable production indicators have been adapted for AM technologies, it was possible to interpret the data from these indicators. It was found, according to Table 3, whether there was relationship between the aspect of sustainable production and indicators with their AM technologies. We found some similarities and other differences that have not leaded to a conclusion if AM can be considered sustainable manufacturing. This analysis only exposed that there are evidences for this state.

Table 3. Identified economic, environmental and social indicators of sustainable production for AM tech.

Aspect for SP	Indicator	FDM	SLA	IPJ	LOM	SLS	3DP
Energy and material use	Fresh water consumption	✓	✓	✓	✓	✓	✓
	Materials used	✓	✓	✓	✓	✓	✓
	Energy used	✓	✓	✓	✓	✓	✓
Natural environment	Waste generated before recycling	✓	✓	✓	✓	✓	✓
	Global warming potential (GWP)	✓	-	-	✓	✓	✓
	Acidification potential	✓	✓	✓	-	✓	✓
	PBT chemicals used	✓	✓	✓	✓	✓	✓
Economic performance	Costs associated with EHS compliance	✓	✓	✓	✓	✓	✓
	Rate of customer complaints and returns	✓	✓	✓	✓	✓	✓
	* Organization’s openness to stakeholder review and participation in decision-making process (scale 1–5).	✓	✓	✓	✓	✓	✓
Community development and social justice	* Community spending and charitable contributions as percent of revenues	✓	✓	✓	✓	✓	✓
	* Number of employees per unit of product or dollar sales	✓	✓	✓	✓	✓	✓
	* Number of community-company partnerships	✓	✓	✓	✓	✓	✓
Workers	* Lost workday injury and illness case rate (LWDII)	✓	✓	✓	✓	✓	✓
	* Rate of employees’suggested improvements in quality, social and EHS performance	✓	✓	✓	✓	✓	✓
	* Turnover rate or average length of service of employees	✓	✓	✓	✓	✓	✓
	* Average number of hours of employee training per year	✓	✓	✓	✓	✓	✓
	* Percent of workers, who report complete job satisfaction	✓	✓	✓	✓	✓	✓

Aspect for SP	Indicator	FDM	SLA	IPJ	LOM	SLS	3DP
Products	* Percent of products designed for disassembly, reuse or recycling.	✓	✓	✓	✓	✓	✓
	* Percent of biodegradable packaging.	✓	✓	✓	✓	✓	✓
	* Percent of products with take-back policies in place	✓	✓	✓	✓	✓	✓

* Depending on organization structure, policies, strategy adapted on sustainable production.

5. Conclusion

Companies need to measure sustainable aspects in order to manage their performance. AM performance still need to include sustainable production indicators in order to be considered sustainable production. In summary those indicators are in the Table 3.

Even though all indicators of sustainable production can be applied on AM technologies, as a common production system, some specific advantages of AM still lack to be counted in this analysis. We might see that,considering the indicators defined for this application are wide and coherent, i.e., it involves sustainable production in economics, environmental and social the measurement do not still show advantages or hide disadvantages. On the other hand, we have also found indications that AM might a sustainable manufacturing through specific indicators for sustainable production.

Thus, it is not possible to assume that AM is a sustainable manufacturing yet. Further studies are still needed to be done and applied The in case studies and different technologies AM.

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Micro Grid Project at Universidade Positivo

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Abstract. A Micro Grid is a part linked to the electric power system that can operate autonomously (islanded) or in parallel connection in accordance with the convenience and needs of both utilities as the final consumer. The Universidade Positivo developed since 2014 one Microgrid project integrating renewable distributed generation such as Micro Hydraulic Power Plant, Photovoltaic Generation Arrangements, Power Generation Wind and Biotechnological processes. This paper presents the details and initial results of the project that already has solar and wind power and should be completed in 2017 with the gradual entry of other sources. It is also being developed a data collection system and monitoring and control in order to provide a detailed and didactic view of the entire system. The Universidade Positivo already applied the islanding of installation through a diesel generating unit that operates at peak times and in emergency interruptions. With the gradual implementation of this Micro Grid project it is already possible to identify the benefits of renewable distributed generation in reducing diesel consumption and the emission of Co2 in the atmosphere. Another important point of this project is the integration of Electrical Engineering, Energy, Mechanical, Computer Science, Civil Engineering and Bio Process where the primary source is variable within the specialty of each engineering and the process output is the electricity, conditioned and controlled.

Keywords. Microgrid, Distributed Generation

Introduction

Probably in the future there will not be just the supply of electric power range of large central power generation, through transmission and large power distribution systems before it reaches consumers.

The distributed generation that has as a concept generating energy on a small scale (few kWs or MWs) near the load, has the significant advantage of higher energy efficiency due to reduced losses and comoum high renewable power level of the sources, especially from solar, wind, biomass and others.

In Brazil Aneel Resolution 482/ 2012 [1] encouraged the micro and minigeneration through renewable energy sources by proposing a power compensation system. The electricity meter installed by distribuiçãolocal dealership must have two-way flow providing the accounting of energy consumed and exported by a particular consumer unit. At the end of a month the balance of this energy is used to assess the energy bill in this period. In this way the consumer can use the distributed generation as a tool to

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reduce your monthly consumption thereby reducing the amount to be paid by the energy bill. This new regulation is causing a significant increase in the number of adhesions. This year 2016 is expected to surpass 2.000 units in the country.

The Microgrids use is made of existing distributed generation and add value and functionality, providing control connection and disconnection of the network, the order of each generation sources and systemic control of components involved in a particular island where the main elements are the loads and generating sources.

The main advantages are the optimization for the electrical system to provide postponement of investments in expansion, improving the quality of energy supply, improvement in stress levels and technical losses. For participants of Micro Grid benefits are the future regulatory compensation for adherence to systemic control, improved confibialidade in providing power to the load and contribute to environmental aspects by the reduction in carbon dioxide emissions due to the use of renewable sources.

1. Micro Grid Universidade Positivo

The Micro Grid Project at Universidade Positivo has the objective of making the campus Ecoville in Curitiba a generation site and Microgeneration Isolated within the concept of Micro Grids.

The University has ISO certification in Environmental Management and adopts an intensive policy of sustainability and contribution to the environment in this context the adoption of a Micro Grid system also contributes to the integration of a model of renewable energy sources to the electrical system.

A diesel generator is used in Campus Ecoville to power loads during peak hours and also serves as a back up to the power of the loads on campus when there ainterrupção in power supply by the local utility. Also in this context the Micro grid system can help generate renewable energy at peak hours or during contingencies , thereby reducing carbon dioxide emissions.

Thus the Micro Grid Project integrates multidisciplinary renewable sources from the point of view of engineering knowledge areas for energy conversion , with automatic control systems , surveillance and communications. These elements are important for the integration and control of generation sources for safety and good energy performance of the system.

Figure 1 shows a representative schematic of energy sources that intend to integrate the Micro Grid Positivo University project.

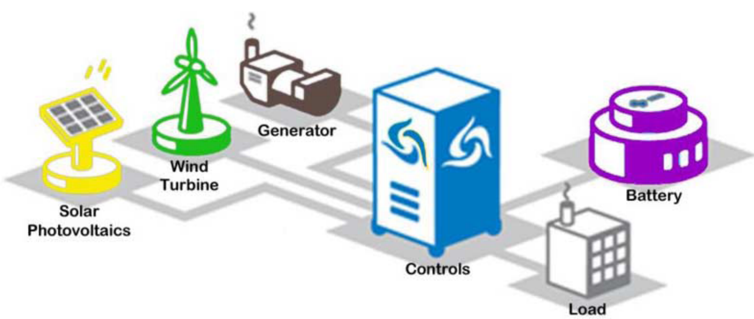

Figure 1. Micro Grid Positivo University Schematic Illustrative

The following sources of energy with their energy uses devised to buy the Micro Grid were chosen :

1 - Thermoelectric Generation Diesel	1 MW
2 - Hidro Generation	1 a 10 kW
3 - Solar Generation	1 a 100 kW
4 - Wind Generation	1 a 3 kW
5 - Biomass Generation	1 a 5 kW
6 - Fuel Cells	1 a 2 kW

Figure 2 shows the future locations of the sources for the Campus Ecoville.

Figure 2. Renewable Sources Campus Ecoville

2. Solar Ferry

The first project developed within the concept of Micro Grid was called Solar Ferry. The concept is based on the possibility of using lakes of water reservoirs, mainly from hydroelectric plants to generate electricity. The basic idea is to cover the area with photovoltaic panels and reduce the evaporation effect of water in the reservoirs in this way takes advantage of the infrastructure transmission or existing power distribution to drain the energy generation plant optimizing resources. Figure 3 shows an illustrative photo of the ferry installed at the Lake University.

Figure 3. Solar ferry on Lake University

The system is composed of eight solar cells 300 with Wp voltage 0 to 40 V continuous current. With the possibility of change in the inclination of the plates for evaluation of the energy generated as shown in Figure 4.

Figure 4. Ferry Solar Photovoltaic Panels Details

2.1. Results of Tests Done

Some records of daily measurements with two days of solar radiation changes were made. Measurements were performed in three photovoltaic panels.

For performance tests of solar panels were used resistive loads of 10 Ohms evaluating the generation under the sun. The voltage uncharged form of 34 V per plate. For measurement of potency was generated using a ZigBee acquisition card with internal AD converter for measuring voltages of the plates. For comparison yields three plates were mounted configurations positioned in different ways. In the computer lab has developed a way PC interface for the collection of data voltages of the three sets of plates every 30 seconds.

In this work involved teachers and students of electrical engineering course , energy and computing.

Table 1. Average voltages and power generated between 7:26 a.m. and 23:59

Panel	Voltage	Power
Panel 1	V = 4,1 V	P = 10 W
Panel 2	V = 3,9 V	P = 10,1 W
Panel 3	V = 3,3 V	P = 3,3 W

Table 2. Maximum voltage and power generated between 7:26 a.m. and 23:59

Panel 1	V = 31 V	P = 213 W
Panel 2	V = 33 V	P = 240 W
Panel 3	V = 10 V	P = 23 W

Table 3. Average voltages and power generated between 7:26 a.m. and 17h (sun period)

Panel 1	V = 10,4 V	P = 34,5 W
Panel 2	V = 10,4 V	P = 38,6 W
Panel 3	V = 5,6 V	P = 8,3 W

Table 4. Maximum voltage and power generated between 7:26 a.m. and 23:59 (sunny day)

Panel 1	V = 32 V	P = 223 W
Panel 2	V = 33 V	P = 240 W
Panel 3	V = 11 V	P = 25 W

Figure 5 illustrates the instantaneous power generated in the solar array, this is a curve of a typical solar generation systems.

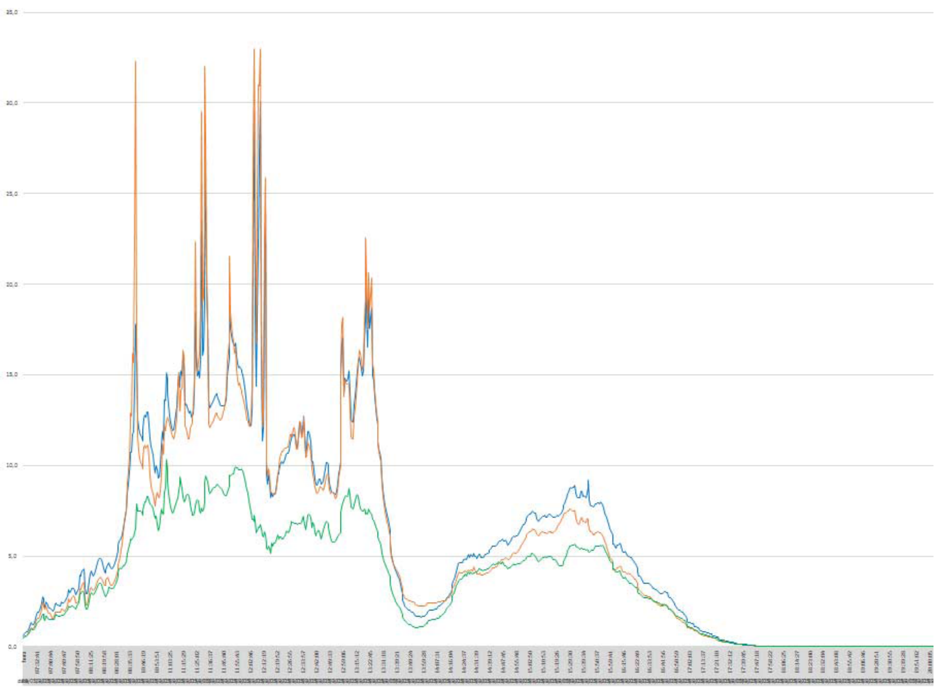

Figure 5. Graph of solar generation systems

3. Wind Power Generator

The second project implemented was a generation system of 3 kW from wind - electric energy conversion. Wind generation of small scale depends on the system of annual average winds of the installation site. In large urban centers to install a wind generation system depends on local and installation height disturbances. The main objective of the project is the evaluation of the application potential in the city of Curitiba and the time chosen for installation (12 meters) . Also there is the evaluation of this project for connection in parallel with the electrical system of the utility called System Grid Tie.

3.1. System Description

The system consists of a horizontal axis turbine with three blades without steering control of these, only mechanical tilt system seeking the greatest friction with air. A synchronous generator Three-phase permanent magnet. An electric brake system, which works in critical situations where mechanical stress speed limit can be exceeded in this system are used electrical resistances. A control system evaluates the minimum voltage generated and operates in controlled rectifying AC / DC, this system is also responsible for the electric brake actuator. The drive connected to the controller output aims to convert the power to DC input for AC voltage with frequency and controlled to meet the requirements for connection in parallel with the electrical system. This CA in output is now made compatible with the network and incorporates the inverter a number of additional protection functions for gantir the connection point not feed faults in the electrical system of the concessionaire. Figure 6 summarizes in block form diagram of the wind power generation process.

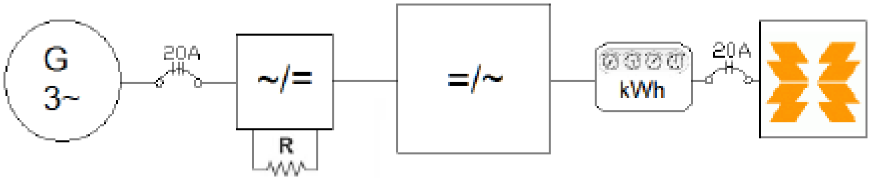

Figure 6. Block Diagram - Wind Generation Grid Tie

3.2. Wind Speed Measurement

For power generation as described in the previous section the minimum speed to start generation is 3m / s and reaches the rated speed of 3kW generation only with winds of 12.5 m / s.

So before the wind turbine installation was designed one stage of field measurements of wind speed values, making possible assess whether the candidate sites for the facility would be suitable energy utilization point of view.

The equipment used to evaluate the wind speed at a given feeder is a digital anemometer with built-in data logger to record the data. Figure 7 shows the anemometer with data logger used to perform some preliminary assessments.

Figure 8 already shows the measurement data of the event rate. There is in many preíodos the generator will be off because can not reach the minimum speed, but has the potential for power generation in some periods. As one of the main objectives of the project is the teaching evaluation system of the generator was installed eventhough periods without power generation.

Figure 7. Anemometer with Data Logger

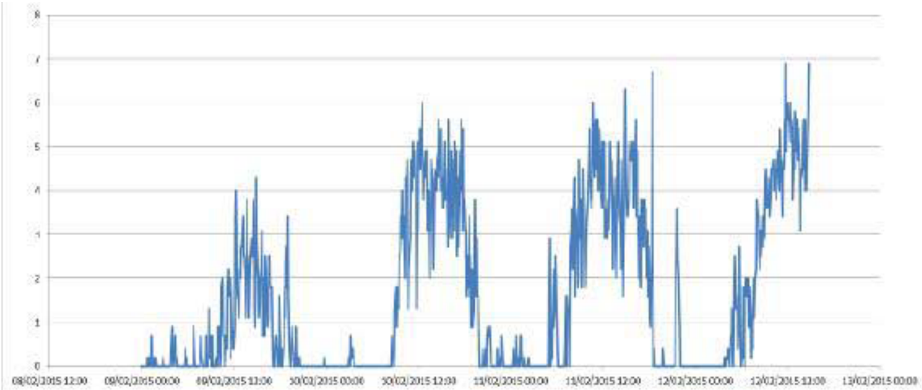

Figure 8. Generation of Wind Power in a period of three days

3.3. Installation at the University

In early 2016 it was carried out of said wind turbine installation activities on campus Ecoville. This activity was accompanied by several multidisciplinary engineering students. As shown in the Figures 9 and 10.

Figure 9. Fixing parts of Wind Turbine in Solo

Figure 10. Final aspect of Wind Turbine Installed

3.4. Values Obtained

Only to register a week of generation can be seen in the chart below the energy behavior of the generator. There has been a long period without power generation, and the generation supply intermittence dependent on a minimum wind speed to start generation process.

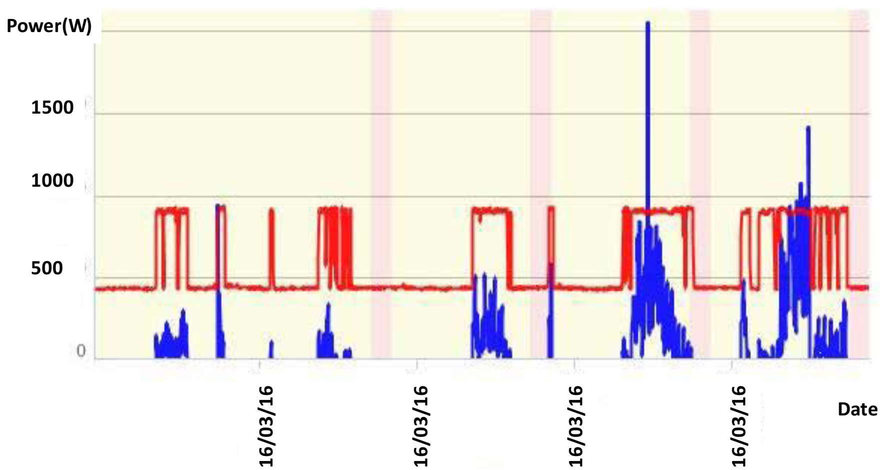

Figure 11. Wind Generation Records

4. Work in Development

In addition to the initiatives also presented there are two important projects underway linked to Micro Grids Project.

4.1. Solar Bridge

The bridge that crosses the lake and connects two important parts of most campus circulation will have its roof covered with photovoltaic panels totaling 52 units and 16 kWp generation.

The main objective of this project is the connection in parallel regime continue with the dealership network and its instrumentation and control available in a didactic way for demonstrations.

4.2. Micro Hydropower Generation

It is running the river flow study that crosses the campus Ecoville. The goal is to install a hydropower generation system using 2 kW turbine screw.
In this case all areas of UP Engineering are working together in the design phase, whose implementation should take place in 2017 .

One of the main objectives of the project is to perform a central control room where all energy sources have their main variables monitored and controlled demonstrating the future concept of control , remote monitoring and dispatching of micro grids .

5. Conclusion

Distributed Generation and microgeneration will undoubtedly be key components in future electric power systems. Micro Grid systems will likely be used in scale especially when the Smart Grid concepts are deployed. Although some regulatory impediments to full implementation in Brazil, Universidade Positivo is developing this multidisciplinary pioneering project among its engineering courses, providing an outdoor laboratory for demonstration of these important concepts.

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Design of a Smart Microgrid Laboratory Platform for University Campus

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Abstract. The smart microgrid platform project has been initiated to integrate a renewable energy laboratory on the campus with real-time data monitoring capacity. This expected smart micro grid will complement the construction process of the campus, as it is planned to be deployed in stages. The overall design of this microgrid laboratory platform is based on the methodologies of system design development processes, where the design goes through different stages such as the informational design stage, the conceptual design stage, the preliminary design stage and finally the detail design stage. All these mentioned stages have their own steps to be followed to get to the desired design of the smart microgrid laboratory system. From the literature research is concluded that there has not yet been made an attempt to design an electrical energy system with the design methods of product or system development process. These design methodologies are actually developed for the design of mechanical and mechatronic systems. The mechatronics are defined at R&D (research and development) level as complex systems which can be organized into ten technical areas: Motion Control, Robotics, Automotive Systems, Intelligent Control, Actuators and Sensors, Modeling and Design, System Integration, Manufacturing, Micro Devices and Optoelectronics, and Vibration and Noise control. Nowadays the application area of mechatronics is remarkably broad. This technology is firmly used in the automation of machines, biomedical systems, energy and power systems, vehicular systems, data communication systems and computer aided design. Since smart microgrids are also complex systems with various integrated elements, the approach of a modified design method of a modular system design was utilized for this laboratory platform. In this context the paper aims to present the initial stages of a modular system design for the smart microgrid lab platform, where the target technical specifications of the smart microgrid system are the key characteristics for the deployment of the modular design as required by the customer. Along the roadmap of this design the main aspects will be presented in this paper, such as the identifications of the stakeholders and clients, the necessities of the customers, the identification of the requirements of the customer and the product/system requirements and the categorization of these requirements with the QFD (Quality Function Deployment or ``House of Quality´´). All the followed steps to be presented in this article will contribute to a structured and analyzed process of the modular design of the smart microgrid laboratory platform to start with the conceptual design stage of this system.

Keywords. Microgrid, Modular design, Renewable energy, Smart (micro)grid, Laboratory platform, Design requirements, Real-time testing, Design stages

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Introduction

Electrical energy has become of great importance to humanity over the past century and defines the features of a modern society. Electricity consume is rooted in many aspects of our lives. The technology evolution has provided people with a varied amount of inventions that establishes our daily tasks and industrial activities and all these products and services have the same point in common, the need for electricity to operate [1].

The electricity generation is undergoing a transformation with the scarcity of resources for the construction of large civil works (dams) and the environmental problems caused by large areas flooding. These events motivate to use new technologies for electricity generation. In order to reduce the dependence on oil and gas, and preserve the environment, the use of renewable energy sources is introduced [2].

To address these challenges in the energy distribution systems, a new concept of power networks is developed, integrating distributed generation and loads associated with them as a single power system unit called the microgrid. The characteristics of microgrid depend primarily on the size and nature of distributed generation units, such as where they are installed and their respective availability of primary power [3].

Micro grids are interconnected with the smart grids; considered to be the basis or basic components of the “macro” Smart grid, allowing the implementation of the smart grid moderately, and introducing the development of interconnected distributed generation without doing harm to the main power system and offer new commercial agreements interest of the supplier/distributor and its clients. The micro grids and the smart grids are based on the same concepts to improve the interconnectivity of all components such as distributed generators with the focus on management and control, reliable energy, environmental issues and economy, [4], [5]. Therefore they are also called smart microgrids. The smart grid can be treated as a state-of the art electric power network framework for different matters such as advanced communication, sensing and metering systems, advanced energy information systems based on demand optimality aspects, advanced control systems and elevated efficiency to [6].

The micro grids are an excellent contribution for research and studies of real main utility grid problems and for the implementation of intelligent systems, because they are smaller grids and consists of almost all the components of the main centralized grid in a small scale [7], [8].

The main objective of this smart microgrid design is to establish a design for a laboratory platform which will be a basic structure for teaching, research, practical tests, analysis and an energy support for the laboratory itself.

This article aims to describe the initial design stage of the design of a smart microgrid laboratory platform for the university campus Gama with a modular system design approach. This smart microgrid will be interconnected with the main local utility grid of the campus, but can also disconnect and support islanded operation. The present work is divided in three sections: the first part provides a brief description of the campus Gama and the smart microgrid project; the second part presents the modular system design approach and roadmap; the third part presents the initial design stage which is the informational design of the modular system, the fourth part presents the conceptual design its first step of this design stage, which is the establishment of the global function and the last part discusses the final considerations.

1. Description of Campus Gama and The Smart Microgrid Project

The University of Brasilia started the construction of a new campus at Gama in year 2008. Campus Gama started in 2008, mainly with the objective to accommodate the undergraduate courses in the field of engineering with five qualifications: automotive; electronics; energy; aerospace and software. Besides these five undergraduate courses, there are also four graduate courses offered: Clinical Engineering, Modeling of Complex Systems (distance), Biomedical Engineering and Engineering Materials Integrity. Actually the campus attends over 1200 students, 120 lecturers and over 100 employees for technical and administrative support. The number of students is expected to grow to a total amount of 2,800 students when the campus is fully implemented.

The Campus has an area of 335,020.95 square meter of Greenland. The planned construction consist 24 buildings with a constructional area of 122,925 square meters of which 3 buildings are already established with a total constructed area of 11,264 square meters. The construction of the campus is planned to be deployed in stages, to be carried out according to the growth on the Campus and to conserve the natural green environment for a green infrastructure.

In Figure 1 is presented the planned infrastructure of the Campus Gama besides the actual infrastructure of the campus. The actual construction of the campus Gama represents three main buildings and a few additional containers which are functioning as small laboratory environments and study areas.

Figure 1. Planned and actual construction of campus Gama.

At present the campus has an apparent power demand of 207.33 kW. The average monthly consumption is 40,000 kWh. The main building and laboratories do not utilize air conditioners, so the demand is currently low. But when the campus grows larger, the demand will definitely increase.

The construction of the campus is planned to be deployed in stages, which will be carried out related to the growth on the campus. One of the main objective of this planning is to conserve the natural green environment for a green infrastructure [9]. Another objective of the campus is to integrate renewable energy generation in their infrastructure to generate green energy and maintain an energy support system. This perception was the first step towards the smart microgrid idea on the campus Gama in year 2012. In the scope of the first perception this smart microgrid laboratory platform design started. A smart micro grid laboratory is very essential on a campus with engineering courses. This facility will be very useful for the different departments, because this laboratory will enhance various engineering courses such as control, automation, computer, electronics and energy. At the same time is taken also into consideration that this campus is in development, with plans for expansion and thereby a growing number of students and professors, where a facility for research, training and education programs in the scope of smart micro grids is a must to keep pace with the growing interest in (smart) micro grid technologies, where many intelligent systems can be integrated in trial. With the smart microgrid laboratory, the experiments and their analysis will deliver students a high level of knowledge to understand the concepts of power system engineering fundamentals and the required demonstrations needed for smart grid implementation in the real world. Educational application of this laboratory-based smart grid and its real-time operation analysis capability provide a platform for research of the most challenging aspects of real utility power system and its operation in real-time.

2. The Modular Design Approach and Roadmap

The proposed smart microgrid laboratory platform can be designed using the fundamentals of the modular design method, which are appropriate for this system, since the smart microgrid laboratory already consist of various elements which can be categorized in module functions. Another reason for this design method is that this final design can be gradually implemented if not capable of financing and constructing the complete system on the campus at once. Modularization of a product or process is described by [10] as the separation of components which are then committed to modules conform a precise arrangement or method. Modularization has three objectives from an engineering view:

1. To allow simultaneous activity.
2. To control complexity.
3. To adapt concerns to come.

Modularity adapts concerns because the specific components of a modular design may be adjusted or alternated suddenly, but has to be according to the design guidelines. Modularization is defined by [11] as a strategy to systematize complex designs and process operations effective by breaking up complex systems into smaller blocks. Hereby the designer can be admitted to work with joint collections of components to evolve and produce a great number of products or systems. The modularity in the design of a complex system permits modules to undergo transformations in the future, without undermining the purpose of the complete system. Hereby is pointed out that the modular design of a complex system is permissive to uncertainty and accepts experimentation in the modules.

[12] described the product architecture of modular design as the event where the physical components are related to functional elements to form different products. These two dimensions in the architecture are defined as follows:

1. The functional one, which is the selection of activities and alterations that supplies to the general functionality of the product.
2. The physical one, which indicates to the selection of physical components and assemblies that facilitates a function.

The architecture could be recognized as an arrangement between components of the product and the assignment of each component.

A systems-level perspective drives the selection of technology platforms and individual components, this is also the case for the proposed smart microgrid laboratory design based on their functional and performance attributes in this work. To propose a method for the microgrid laboratory platform project a roadmap was made throughout this work. In this article the modular system design will be presented up to the first step of phase 2; the conceptual design. The general roadmap for the design of this modular system is presented in Figure 2.

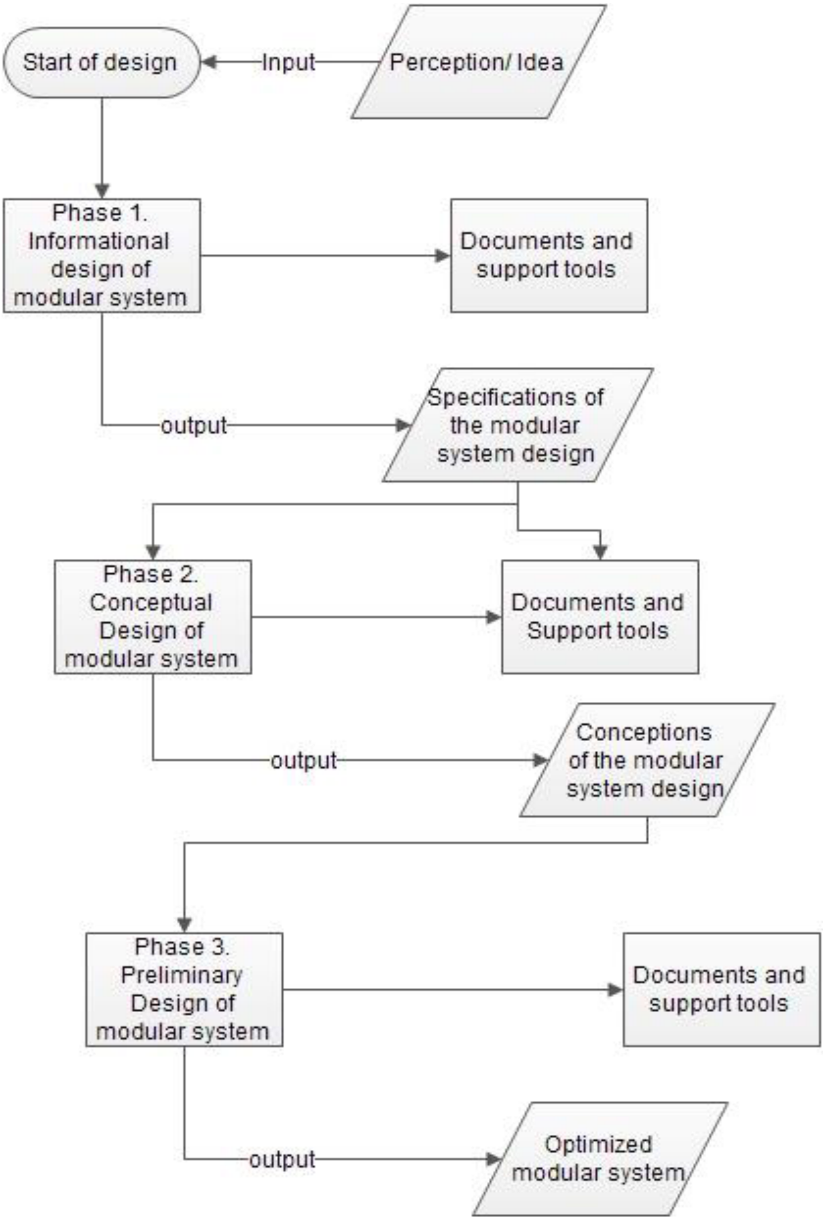

Figure 2. Roadmap of the smart microgrid modular system design.

3. Informational Design of Modular Smart Microgrid System

The informational design of modular system corresponds to methods and techniques to help the designer to clarify the problem presented by the design, in order to support him in two aspects namely: define the design problem to study and establish specifications for the development of the design. The term "informational project" was established with the need to standardize the stages of design process, as to put them all in the design level. In other words, until recently the informational design was called "definition of design problem" [13]. This informational design phase of the design process is shown in Figure 3. Hereby are presented the tasks of each step and the support tools or documents used along the process of the design. The input and output in each stage is of importance to be able to follow the procedure and understand the correlation between these stages in the design process.

Table 1. Informational design of the smart microgrid modular system.

Phase 1: Informational Design of Modular system		Input	Output	Documents and Support Tools
Stage 1.1	Task1 Search for information to clarify the problem and establish the life-cycle of the system	Collected Information to contextualize the problem	Clarification of the problem	Life-cycle of the system/product
Stage 1.2	Task 2 Identify clients and their necessities	Goals to be achieved	List of necessities of the clients	Life-cycle of the system/product
Stage 1.3	Establish the requirements of the clients of the modular system	Needs of the clients	List of requirements of the clients	Transformation method of the necessities in requirements of the clients
Stage 1.4	Establish the requirements of the modular system design	Requirements of the clients	Requirements of the design	Mudge Diagram and transformation of the client´s requirements into design requirements
Stage 1.5	Prioritize the design requirements of the modular system	Requirements of the design	Design requirements classified by level of importance	Matrix of Quality function Deployment (QFD)
Stage 1.6	Establish the smart microgrid modular system specifications	Design requirements classified by level of importance	Design requirements specified to meet the modular system design	Table of the smart microgrid modular system design specifications

Stage 1.1 upto stage 1.4 as presented in Table 1, are all concluded in the life-cycle of the smart microgrid system. The product/system life cycle is a supporting document to the design process to register the needs of various clients involved in the development of a product or system. This life-cycle is presented in Table 2. The requirements of the clients are transformed from the necessities for each life cycle fase. After the identification of the needs, initially described according to the language of customers, they can be rewritten in the form called requirements of the customer. The requirements can be functional (what the product needs to do) or nonfunctional (the qualities that the product must have) and restrictions are global requirements of the product.

Table 2. Life cycle of the system.

Life cycle of the system	Requirements of the client	Identification of stakeholders/ clients
Planning	To be a safe and secure power system architecture for experiments	Project manager, Project financier, Institution/Universities, governmental energy legislators
	To support low carbon emission power generation	Students,Reseachers,Green energy organizations;
Design	To have a two-way flow of electricity and information	Smart metering (technology) suppliers
	To be utilising an overall power system control	Power electronics suppliers
	To enhance a plug-and-play infrasrtucture	Platform construction team (students, contractors etc)
Testing	To integrate measuring systems for different parameters	Measurement systems suppliers
	To predict system behavior	Educational institution
Operation	To prevent black-outs	Microgrid operators, utility grid operators
	To operate in different scenarios	Smart metering systems suppliers
	To enable remote operation	
Maintenance	To be a low maintenance power system	Smart metering systems suppliers
Monitor & Control	To be a self-healing microgrid	Control & monitoring systems/software suppliers
	To implement control strategies for generating units & power transfer to the loads	Power management (EMS) and control systems suppliers
	To be monitoring all system parameters	
	To consist demand-side- and outage- management	

Stage 1.5 represents a tool used to accomplish the prioritization of system requirements which is called the House of Quality Matrix or QFD (Quality Function Deployment). The objective is to prioritize the system requirements transformed from the needs and desires of the customers in the system design process, serving as a basic plan for the conceptual design of the system. A correlation is made between the customer´s requirements and system/product requirements, to establish the level of importance of each requirement of the system. With this information, the designer can

prioritize design decisions in favor of those considered the most important requirements [14].

Stage 1.6 enhances the results of the QFD and presents the technical specifications of the proposed smart microgrid design. Table 3 illustrates part of the these technical specifications of the smart microgrid laboratory system elaborated from the QFD.

Table 3. Part of the specifications of the smart microgrid system.

Specifications	Metric-Unit	Objectives	Sensor	Undesirable output
High level of supervisory control system	seconds (s); minutes(min);and hours (h)	Aims to achieve an optimal operation	Measure power, current and voltage	Not detecting the over load situations
High level ofcommunication system	Kbps; or Mbps at frequency (Hz)	To monitor the overall power system from a distance (not locally) in real-time	Transporting data to monitoring and control systems	Not functioning communication
High remote monitoring system capacity	Mbps or kbps at Hz	Parameters can be monitored through remote monitoring system	Wireless sensor systems to sense the data of the microgrid parameters	Failure of remote monitoring system
High level of monitoring via software systems such as SCADA	seconds (s) or minutes	Generation of charts and reports with historical data; Detection of alarms and automated event logging	Transformation of the analog data into digital data	Shutting down of the power system

4. The Conceptual Design

The conceptual design is the phase of the design process that generates a design of a system from a detected and clear need of the customers to meet their need in the best possible way. The conceptual design includes two major sub phases: functional analysis and synthesis of solutions. In this second phase of the design process, the system is being modeled primarily in terms of the function that the system is capable of performing as a whole, then in terms of reduced complexity of the functional structures representing the full function of the product [15].

In Figure 2 is presented the global function of this smart microgrid system. In the functional modeling, the first task in the search for a structure of functions for the system to be designed is to create a global function model of this system. The global function is the total function of the system which must express the main function (or main functions) of a system trough the relationship between their inputs and outputs. This task is the correlation of the consumer needs, defined in Phase 1, by an overall function of the system.

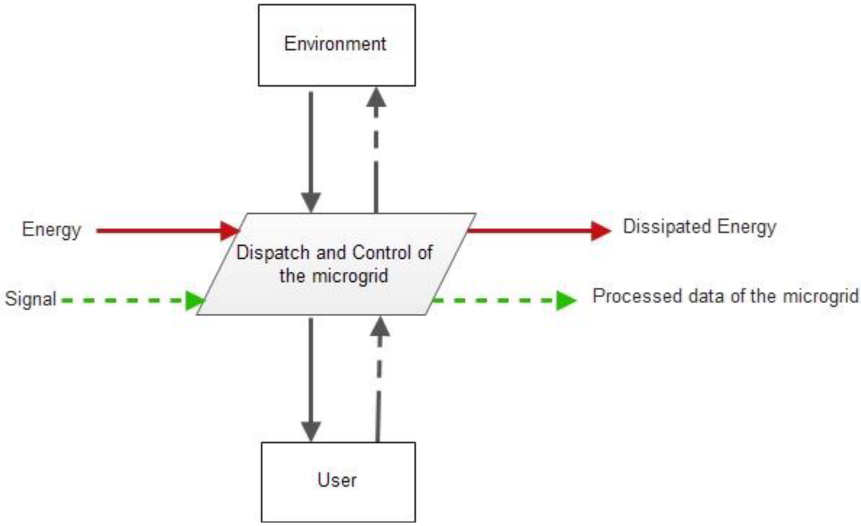

Figure 3. Global function of the smart microgrid system.

5. Final Remarks

This paper presents a part of the modular system design approach of the smart microgrid system. The first phase is here presented as the informational design phase. The importancy of this phase is the establishment of the specifications of the smart microgrid platform with the defined requirements of the system to be designed through different tools and documents as known in the design of products or systems. In this work is elaborated the modular system method approach, because the methodologies of the modular system are used throughout the design. The design of the smart microgrid laboratory platform for the university campus is divided in stages and steps with their inputs and outputs. The life cycle of the system presents the stages through which the smart microgrid platform goes from the beginning of the design process up to the end of the system, where the design is completed and the system is already in full operation in this case. In this work is finally presented the first step of the conceptual design phase, that enhances a process that is also divided in different stages. The first step of the conceptual design phase is here the establishment of the functional structure of the smart microgrid platform. In this work is presented the global function of the system as the first step, whereby the next stage will be to define the partial functions and the elementary functions. These functions will represent the overall functions of the smart microgrid system design. Through the roadmap followed for the design of the smart microgrid system, the next step in the conceptual design phase will be the identification of the modules of the smart microgrid system. These modules will enable the design of a modular system for the smart microgrid platform of the university campus, to be developed in stages.

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Socio-Technical System Design to Offer Specialty Coffee Ready for Consumption

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Abstract. This study presents the conceptual basis for the design of a new system to deliver specialty coffee ready for consumption produced by small farmers. The challenge of the new socio-technical system design is the balance between economic, environmental and social elements, in addition to the technology. The interaction of these elements should lead to a result that meets the development of appropriate technology requirements. This requires the application of a systematic process. Although projects for small producers are generally not treated within the theory of complex systems, there is a variety of features that may be presented in a socio-technical system, causing different treatment in order to analyse them.

Keywords. System development process, product development process, complex systems, specialty coffee.

Introduction

The technology explosive advances in recent years has been one of the biggest factors for the emergence of systems engineering as a key ingredient in the design of complex systems. These advances haven't affected only the products but also fundamentally changed the way they are designed, produced and used [1].

It is widely accepted by the academy that new products, which are developed on a systematic basis, are one of the factors that guarantee the sustainability of the success of organizations [2]. In this scenario, the product design has been integrated into the system design and the service design, even knowing that the starting point of the discussion of the term "project" was in mechanical engineering [3].

Furthermore, the industry development tends to short innovation processes, to an emerging customer integration in product development, and to an increased degree of multidisciplinary during the product design [4].

The product complexity can be directly related to the number of systems contained therein, the number of subsystems in each of the systems, the number of components in each subsystem and the number of interfaces between different components, subsystems and systems [5].

There isn't a formal definition for complex systems. Informally, it is a large network of relatively simple components which do not have a central control, but it is possible to observe and emergent complex behaviour. It is known that an agricultural system responds to few present challenges aiming to coordinate different components, increasing complexity and, then, the system can be characterized as complex [6].

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In a previous survey conducted with support from the Brazilian Agricultural Research Corporation (EMBRAPA) and the Brazilian Micro and Small Business Support Service (SEBRAE) on the production of specialty coffee in small farms of *Minas Gerais* (Brazilian Southeast state) and *Paraná* (Brazilian South state) it was identified that most of the production of specialty coffee produced by the farmers studied it is exported as green beans [7].

Regarding the formation of agricultural activities considering differences, tradition, use conditions and technical knowledge among farmers, the technical solution to be adopted must consider the human factors involved. It was then observed the necessity to design a new socio-technical system to deliver coffee ready for consumption produced by small producers. Adopting a socio-technical approach to system development leads to systems that are more acceptable to end users and deliver better value to stakeholders [8].

Based on the results of the research mentioned, the work of [9] and the scenario presented, this article purpose is to present the conceptual basis for the design of this new system for delivery of specialty coffee ready for consumption produced by small farmers.

The challenge of designing this socio-technical system is the balance between economic, environmental and social elements, in addition to technology. The interaction of these elements should lead to a result that meets the development requirements of appropriate technologies, which demands a systematized process to develop products.

The appropriate technology in the development of an agricultural production system is conceptualized through the following specific features: low investment per job, low capital investment per unit produced, potential for job generation, organizational simplicity, small-scale production, high degree of adaptability to the sociocultural environment, local and regional self-sufficiency, natural resources economic use, renewable resources and social control preferable use [10].

This study adhered to develop their activities using the qualitative literature, selecting what to adapt to the small coffee producer's scenario. Thus, the structure of the article is organized as follows: starting with the product development process, through systems development process to finally present the research environment that will be object of future works.

1. Product Development Process

A new product development consists of a set of activities which seeks to achieve product design specifications and its manufacturing process so that industry can produce it. It starts from the market necessities and the possibilities or technological constraints, considering the competitive product and company strategies [11].

Moreover, the follow up after the product launch is also included in the product development process to make any necessary changes to its specification. Also the plan to discontinue the product on the market and incorporate the lessons learned throughout the product life cycle to the development process [11].

The literature presents some reference models for product development ([11] [12] [13] [14] [15] [16] [17] [18]). In their works each author interprets the process of product development from a different perspective. But most of them have models divided into steps or stages and due to this generalization may vary substantially from industry to industry. Many models of the product development process are similar, however, differ in the number of steps or stages [19].

The product development process presents specific features when compared to other business processes. These features are: high degree of uncertainty and risk of activities and results; important decisions must be made early in the process, when the uncertainties are even greater; difficulty of changing the initial decisions; basic activities follow an iterative type cycle: Design (generate alternatives) - Build - Test - Optimize; handling and generation of high volumes of information; information and activities come from different sources and areas of the company and the supply chain; multiplicity of requirements to be met by the process, considering all stages of the product life cycle and its customers [11].

Figure 1 illustrates one of the mentioned models, which was developed by [11], and shows the stages that have been established. The stages are: the planning of the product, the informational design, conceptual design, detailed design, preparation for production and the product launch.

The first stage is the product planning regarding the understanding of product participation in the company's strategy to investigate, especially, its viability and its market share. The informational project's ultimate goal is to develop a set of product specifications as complete as possible. This information is used by conceptual design stage to generate a detailed representation. Then all settings previously made are transformed into manufacturing processes presenting the final product configuration. Finally, preparation for production will approve and release the product to the factory to do its launch [11].

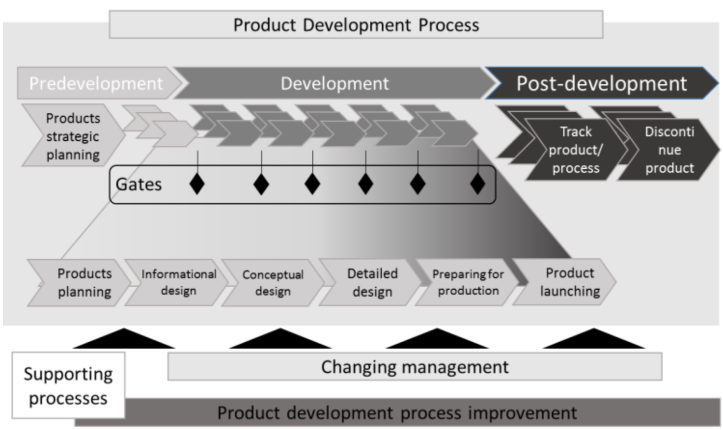

Figure 1. Product Development Process [11].

The author creates development stage steps, but he also pointed out the activities that are related to it, such as the pre development stage, responsible for strategic product planning, the post-development stage that is concerned with monitoring and discontinuation of the product and also the change management process.

Therefore, it is through the product development process that the system will be designed, but it will be guided by principles of systems engineering, because it is a complex system. This concept will be addressed in the next topic.

2. System Development Process

The systems engineering differs from other disciplines because it is focused on the system as a whole; because it is concerned with the needs of customers and the operating environment; because it leads the system conceptual design; and finally, because it creates a bridge between traditional themes and specificities [1].

Complementing, systems engineering is a process of multidisciplinary decision-making involving design and use of systems and products. This process is made up of both technical activities and management from the initial phase of the project until the product or system life cycle end [5].

Taking this into consideration, there are some approaches to systems development process in the literature: [1] [5] [20] [21] [22] and [23].

The NASA Systems Engineering Process is the best known. This process describes the development in 17 steps by grouping them into three different groups: system design, product realization and management [21].

The first group comprises the first four steps and concerns the definition of stakeholder expectations, the basic technical requirements generation and the conversion of these requirements in a design solution that will meet the expectations previously identified [21]. The authors noted that these steps are applied to each system product starting from the highest level and decomposing to the lowest level of detail.

The second group, called the Product Realization, starts from the lowest to highest product level of detail and search for each of them to create a design solution. As this is completed, the solution is checked and validated and then goes to the next level.

The third and final step is responsible for establishing and developing plans for project communication to maintain the interfaces and ensure the progress of product development, to control the execution of the project until its completion and to assist in the necessary decisions. Figure 2 shows these stages.

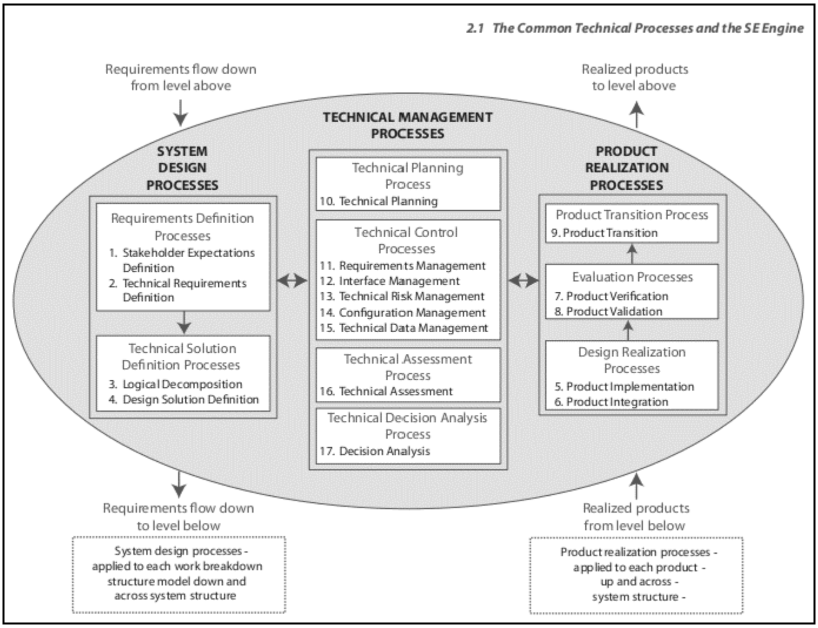

Figure 2. NASA Systems development process [21].

In its Handbook, NASA states that the systems engineering process is both iterative and recursive. This is because the product application repetitively allows the correction of discrepancies or changes in requirements, and add value to the system exactly through this repetitive application layer by layer of the system [21].

In summary, the product design process is considered a set of activities that guide the project team to the system design. As well as systems engineering that provides models, methods and tools required to solve complex problems.

The initial stages of both methodologies, called Informational Design and System Design, provide for the insertion of the customer's perspective to define the system's features. Therefore, it is important to turn these expectations or needs into requirements to ensure a set of representative technical specifications. It is expected that different approaches will be captured for systems with agricultural activities and that they will also result in different requirements.

System requirements are services descriptions provided by the system itself and its functional constraints, reflecting the customer's needs. User requirements are customer expectations (or stakeholders) on the product (or system) in terms of mission, objectives, functions, environment and constraints. The requirements of human factors are requirements for the product (or lower system level, subsystem or component) to ensure that people can perform their duties in comfort and with ease while using the system [24].

3. Research Background

After presenting the conceptual basis of this work this topic will describe the research environment which these concepts will be inserted in the future. The model that will be used to present the background was a result of previous research. It is important to notice that the survey was conducted in the context of supply chain and it is used in this paper as a mechanism to describe the scenario that the new socio-technical system will be developed. The model wasn't tested in others contexts beyond the specialty coffee.

Two regions were interviewed represented by: a development project manager from Paraná; a president of the cooperative and producer from Paraná; the seed and coffee producer from Minas Gerais; three Minas Gerais coffee producers.

The first region interviewed was in the state of *Minas Gerais*, represented by coffee and seed producer from *Cerrado Mineiro* which is inserted in an Origin Denomination. The region was also represented by a coffee producer from *Zona da Mata Mineira* region in the east of the state, which also is part of the local association. Besides, others two producers in the southern region of *Minas Gerais*, representing the Regional Provenance Indication. Then the northern *Paraná* was studied by means of a coffee producer and also by the main development project manager currently developed in the area.

All properties interviewed were small or medium, large producing properties of coffee, with sales on a large scale, were not considered. Finally, in all the interviews, the information was collected only about specialty coffee, according to the classification of [25]. Figure 3 was a result of this research and shows the practices that were observed during the interviews.

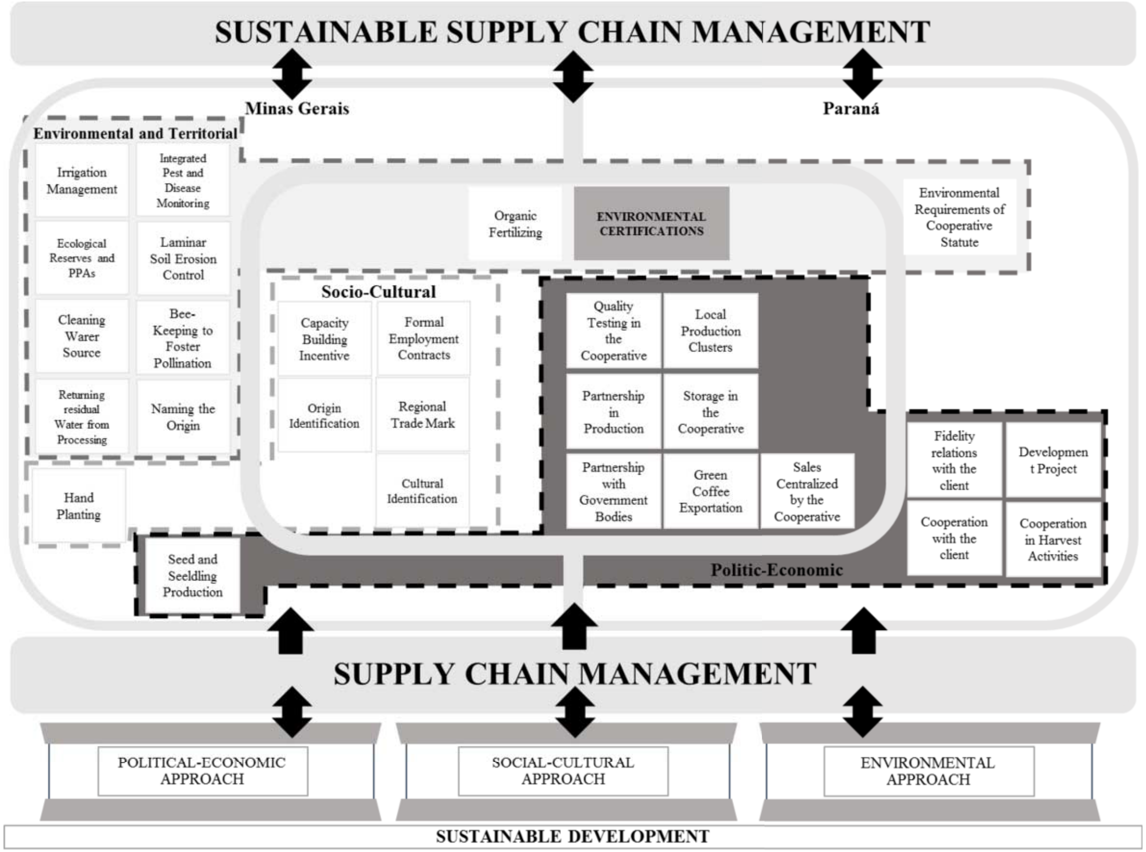

Figure 3. Practices observed in the case study [7].

The purpose of this figure is to provide a broader and more solid analysis concerning the use of concepts such as eco-design, loyalty buyers, environmental certification, cooperation, geographical indication, among others.

Figure 3 demonstrate in the centre the practices that are common to both regions and in the borders the ones that are peculiar to each of them. The idea is that at the bottom of the square there are two concepts that form the basis to achieve a sustainable supply chain management, which are supply chain management and sustainable development. In this sense, when a company walks from the bottom and uses some of the practices presented in the middle they will guarantee a sustainable supply chain management.

Different product markets have in common the emergence of a paradigm based on the quality of products and production processes. The value is related to a linked notoriety not only the well appropriated, but also to own product formed by recognizable signs that it carries [26].

Coffee then becomes a well endowed with symbolic values that is related to the area history in which the grain was produced, the technology and processes adopted in the extraction, the grain denomination and the trained professional denomination [27].

There are companies in Brazil that develop genuinely national innovations, i.e. changes representing new to the world market. These cases usually are limited to domestic companies, which are positioned between the leaders on the world market and therefore inserted in more competitive markets [28].

These companies have expertise and sufficient financial resources (or the possibility of raising these funds) to go against other companies in terms of innovation. These social actors tend to work in smaller markets (regional and local) and tend to be followers and not innovative, even for the sake of financial capacity. In general, they observe the large ones to innovate its products or processes; these are companies that "copy" what has already been launched in the domestic market to meet the consumer and to compete, as a matter of survival. The launch of vacuum packaging in cafes or mill adoption roller for smaller companies are examples of such innovative efforts [28].

Despite not having significant participation in the Brazilian coffee production history, a market research on the specialty coffee consumption in Brazil ([25]; [29]) show an opportunity for small producers heating up production of specialty coffee ready for consumption.

Considering the current sales price presented by some specialty coffees, the difference is between 30% and 40% more in relation to coffee grown conventionally, and in some cases, can overcome the barrier of 100% [25]. This reinforces the need to develop new systems that are appropriate to their reality.

Projects involving small farmers are usually developed within the appropriate technologies context, it does not always bring the best returns for different parties involved in the project, often requires a long benefit period and grants without system sustainability assurance [30].

4. Final Considerations

This research fulfils its purpose of presenting the conceptual basis for the design of a new system for delivery of specialty coffee ready for consumption produced by small farmers. This is because the product development process and the system development process was founded to be sufficient to offer the tools and mechanisms needed to design it.

Therefore, it can be said that the projects for small producers are generally not treated within the theory of complex systems. On the other hand, it is important to emphasize the variety of features that may be present in a complex system, and causing different treatment in order to analyse them [1].

The complex systems are able to exhibit one or more of the following characteristics: some degree of unpredictability; assortment of components which are highly interconnected and the behaviour of the entire system depends significantly in the interactions between its components; certain level of autonomy; its components are individuals or autonomous elements; adaptive, able to learn, grow and respond to environmental stimuli; self-organized, and the whole system emerges as a result of cooperation and competition of its components; emergent properties and behaviours are considered key features [31].

In this sense, it is reaffirmed the need to adopt a systemic approach for building effective and efficient solutions presented in the coffee scenario, added to the uncertainties presented in a sector characterized by constant change.

The product development process is considered as set of activities that guide the project team to the system design. As well as systems engineering that provides models, methods and tools required to solve complex problems.

The definition of the conceptual basis performed in this work also contributes to plan this research future activity. Based on methodological proposals in [11] [12] [13] [14] [15] [16] [17] and [18] on product development process and [1] [5] [20] [21] [22] and [23] focused on systems engineering. The project was divided into two phases. The first focused in the system requirements definition, and the second focused on the development of the system design or conceptual design phase. As illustrated in Figure 1.

The first phase involves the systematization of knowledge for the development of system requirements which is also known in the literature as informational design stage or engineering requirements. At this stage from the needs of those involved in the different phases of the system lifecycle draws up the technical specifications of the system. These specifications form the basis for driving decision making in the next stages.

One of the main challenges during the beginning of the project is the integration between different areas of knowledge intending to use the needs and system maintenance. This requires the use of objective collaboration techniques sharing experiences, ideas, resources and responsibilities between the parties involved in the project.

It was observed that the systems engineering used as a methodology for designing a system would serve as a mechanism to introduce the customer needs in a systematic way. The starting point to construct this system is the requirements definition that need to be understood and analysed at every step through the subsystems and components.

Thus, mechanisms within an organization to help promote and structure the transfer of scientific and engineering knowledge in order to meet consumer needs, can help promote innovation. The life cycle model adopted by systems engineering would be one such mechanism [32].

The conceptual design phase is characterized by the exploration, creation, representation and selection of solutions for system design problem. The existing solutions search can be made by observation of existing products described in books, articles, catalogues or patent database. The representation of the solutions may be made by diagrams, sketches and drawings computer. The selection of the solution is based on appropriate methods that rely on technical specifications generated in the informational design phase.

Finally, in this context it was observed during this work that the conceptual basis contributes to the design of a new production system for generating income of small farmers. It also contributes to the implementation of systems engineering theory out of context development of computer systems.

This follows from the statement that the systems engineering has often been understood as a synonym for engineering computer systems. The practice of design and development of systems engineering in general, however, has shown that the work systematization and systems engineering tools are essential in the creation of complex engineering systems [33].

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Part 5

Systems Engineering

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Transdisciplinary Engineering: Crossing Boundaries
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A Notification-Oriented Approach for Systems Requirements Engineering

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Abstract. Systems Engineering (SE) is an approach for designing complex systems in a multidisciplinary universe, based on concepts from the systemic paradigm and promoting languages, methods, and standardized processes. Requirements engineering is one of the main steps in SE processes. The current research presented in this paper aims at focusing on the open issue related to the formalization of systems requirements for their verification, ensuring the coherence of the whole set of requirements in each contextual engineering domain and their validation against the initial stakeholders' needs. Moreover, requirements coming from different domains are generally linked by non-formalised traceability relationships. It is even difficult to trace any change in their definition and their impact to the whole set of specifications. The paper discusses and proposes an approach for systems requirements engineering based on a rule and notification oriented approach for ensuring the effective coherence and understanding of these requirements throughout the life cycle of any complex system. This proposed notification approach is derived from the so-called Notification Oriented Paradigm (NOP), a new rule and event driven approach for software and hardware specification and execution.

Keywords. Systems Requirements Engineering, System Specification, Notification Oriented Paradigm

Introduction

Currently, in order to face globalization and the resulting increased competition, enterprises have specialized in specific domains and have established partnerships with other companies to complement their initial skills. These enterprises are thus forming a so-called collaborative and distributed network. These approaches have allowed them to develop complex systems and collaborative activities in many industrial domains like aeronautics, nanotechnology, aerospace, and bioengineering.

According to [1], it is important, for succeeding in these collaborative engineering processes, to formalize how different partners can work with others and, through their interactions, how they can achieve a common objective within different perspectives.

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These engineering processes follow best practises generally defined in the so-called systems engineering domain.

Systems Engineering (SE) is an approach for designing complex systems in a multidisciplinary universe, based on concepts from the systemic paradigm and promoting languages, methods, and standardized processes (ISO/IEC 15288) [1]. It aims at consolidating, identifying, and formalizing new methods and frameworks that support engineering phases in a better consistent way [2]. It is "an interdisciplinary approach and means to enable the realization of successful systems" [3]. One of the SE processes is dedicated to analysing users' and systems' requirements.

Requirements Engineering (RE) refers to the activity of formulating, documenting and maintaining systems requirements [4] in order to produce, from users' needs, a set of specification related to what the final system should be. Requirements provide the basis for all phases of the development system. Thus, it is necessary to control these requirements in all phases of the development cycle and in all domains to avoid some misinterpretation and mistakes committing the final results.

A requirement is a statement from the stakeholder's needs in order to define a product, a system or a process and it must be unambiguous, clear, unique, consistent, stand-alone, and verifiable [5]. Each requirement matches a single part of the future product, system or process and it is grouped in an appropriate combination of textual statement views. Whereas approaches such as the Model-Based Systems Engineering (MBSE) have been studied [6][7] for improving the definition and the coherency of requirements [8], there is still difficulties to ensure that coherency from a semantic point of view and to identify all impact relationships when any of these requirements change during the system development lifecycle.

1. Related Works

Requirements Engineering has long been recognized as critical activity in systems and software development processes [9][10][11]. A large amount of studies addresses theoretical aspects and propositions of techniques and recommended practices for RE [12]. Hofmann and Lehner [13] identified RE practices that clearly contribute to (software) project success and concluded that successful projects allocate a significantly higher amount of resources to RE (28%). Many (37%) of projects failures [14] are caused by the problems of requirements misinterpretation among stakeholders. Most studies have focused on requirements elicitation, modelling, and processes/methods 1395–1410
[15][16].

A number of researches reported in the literature focus on the elicitation of requirements. According to [17], this activity is the process of seeking, uncovering, acquiring, and elaborating requirements for (software) systems. It concerns learning and understanding the needs of the customer with the aim to communicate these needs to the developers [18]. Additionally, there is a general agreement [19] that fixing the results of poor requirements elicitation is more expensive than for other mistakes. It is a common sense in most studies that systems requirements have to satisfy the customer´s (i.e. stakeholders) intents. The ISO/IEC/IEEE standard uses the expression "in a way that is (the requirement) acceptable to the customer" [20] to emphasize that the requirements must achieve the customer´s intentions. Thus, some authors propose to validate the specified requirements by determining their conformity with stakeholders´

needs [13]. The term "need" is often employed to refer to the cause or reason that justifies the specified requirements [18]. The needs would be the source of the requirements. Some authors, inspired by INCOSE[2] observe that the stakeholders' needs in turn contribute to the solution of some real-world problems [21][22].

In the context of systems engineering, the deep understanding of a system's intents and how they maps to systems requirements is as important as for software engineering, and the underlying concepts are also analogous. INCOSE employs the terms "Problem or Opportunity" to refer to the issues underlying the gaps in the organization strategy with respect to the desired organization goals or objectives [5]. In spite of the large number of studies and approaches proposed to specify systems requirements, for any "complex system" development (e.g. software, aerospace, automotive), it is a common agreement that requirements engineering remains an unclear and challenging task. Terms used in scientific literature and even in the industry (as pointed out in this section) are not convergent creating a lack of understanding on the subject. Analysts may feel confused when trying gathering information from the stakeholders and other sources in the business or application domain. Therefore, the specification of the studied system may become incomplete or incorrect because of an inadequate understanding of the project intents.

Generally speaking, the various works on requirements engineering show that there are two unsolved main issues/questions [9] that this paper tackles in the proposed approach: (1) how to "semi-automatically" model a set of requirements taking into account their strong inter-relationships? (2) How to identify/formalise these inter-relationships that are generally domain-dependent and thus related to some deep and implicit knowledge of the related skills of the stakeholders? [23]

This paper discusses and proposes a solution only for the first question. Indeed, the model of all requirements of a system and their inter-relationships can be seen as a bi-graph of interrelated notifications where each requirement is a logical premise manipulating some systems attributes and notifying some functional entities which, in turn, forward new attributes values to any impacted requirement. This operational semantics is quite analogue of the so-called NOP paradigm that we will discuss briefly in the following section.

2. Notification-Oriented Paradigm (NOP)

A new technique, called Notification Oriented Paradigm (NOP), was proposed as new software programming and developing approach. NOP presents a new concept to develop and execute applications. Its essence is an inference process based on small, smart, and decoupled pieces of software (i.e. entities) that collaborate by means of notifications. This solves redundancies and centralization problems of the causal processing, thereby solving processing capacity misuse and coupling issues. In NOP, causal expressions are represented by a set of logic-causal rules and dealt by entities called *Rules*. A *Rule* entity, represented as a logical and causal expression, is illustrated in Figure 1 (a). Structurally, a *Rule* entity has a *Condition* entity and an *Action* entity which respectively concern the decisional part and the execution part. Each element evaluated by a *Rule* set is represented and dealt by an entity called *Fact Base Element* (*FBE*). In the considered example, the *FBEs* are the *Security_System and User_Reader*.

[2] International Council on Systems Engineering, http://www.incose.org

A *FBE* comprises one or more *Attribute* entities that store data. Examples of *Attributes* are the *Status* in the *FBE Security_System* and the *Bio* in the *FBE User Reader*.

The values of *Attributes* are analysable, in an inference process, by the *Conditions* of *Rules*, using other collaborative entities called *Premise*. In the considered *Rule* (Figure 1 (a)), its *Condition* comprises two *Premises*. When each *Premise* of a *Condition* is inferred as true, the related *Rule* becomes enabled and it can activate its *Action* composed of entities called *Instigation*. In the considered *Rule*, the *Action* has one *Instigation*. In fact, *Instigations* are linked to *Methods* of *FBEs* to execute services. In the *Action* of that *Rule*, the *Method Activate_Alarm()* is instigated. Commonly, instigating a *Method* of an FBE changes the values of *Attributes* [24][25].

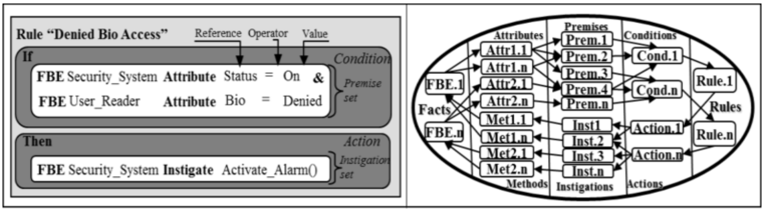

Figure 1. (a) The Representation of a NOP *Rule*. (b) NOP Components and Notification Chain.

The NOP inference process is innovative. Indeed, the *Rules* do not become enabled by matching *Attribute* values by means of some usual search approach, but by evaluating their *Conditions* when they are notified by *FBEs* that *Attributes*' values changed. Inference happens in the following way: for each change in an *Attribute* value of a *FBE*, based on the new value, just the very pertinent *Premises* are notified and make its logical analysis; for each change in a Premise logical state, it notify just the very pertinent *Conditions*. In turn, *Conditions* enable new *Rules* that may execute *Actions* by notifying *Instigations* which in turn execute *Methods* of *FBEs*. The collaboration between NOP elements by means of notifications is illustrated in Figure 1 (b). This notification chain is created during the software compilation phase [24][25].

3. Proposed Approach for Systems Requirements Engineering

3.1. NOP Modelling Primitives

According to the NOP specification [25], the NOP modelling primitives essentially includes *Rules*, *FBEs*, and *Notifications*. These building blocks allow describing the entire logic of software systems. Additional primitives may be employed to specify particular constraints, aspects of software flow control, and conflict solving, among other features of the system being modelled. In the proposed approach for systems requirements engineering, the authors make use of the three main NOP primitives in order to describe those requirements at the same level of detail then those sentences expressed previously by the system engineer, according to the information expressed by the stakeholders. The meaning of the three NOP primitives in the context of this paper are described in the next topics.

Rule - A *Rule* in NOP is defined as a logical unit, which commands a set of actions when its conditions are satisfied. In the proposed approach, a *Rule* represents part of or an entire system requirement, including the constraints with regard the needed conditions (i.e. *Rule* preconditions) for that requirement and the effects or actions to be accomplished (i.e. *Rule* post-conditions) according to that requirement. Depending on the system requirement complexity, one or more rules may be composed to express each requirement. The notation to draw a *Rule* is depicted in Figure 2 (a).

Fact Base Element (*FBE*) - In NOP, an *FBE* represents a software element, which may contain *Attributes*, can carry out functions in *Methods*, and can interface with external elements (e.g. user interface, sensors, and devices) also by means of *Methods*. In this paper, when specifying systems requirements, authors also propose to use *FBE* to represent system elements identified in the requirements *statements*. This way, *FBEs* are limited to the elements known at the requirements specification phase. *FBEs* are drawn as dashed rectangles in the proposed notation as illustrated in Figure 2 (b). They must contain one or more exposed *Attributes* that represent notified events or variables. A *FBE* may also contain incoming arrows that represent functions called by other FBEs.

Notification - A *notification* is an explicit advice from a NOP element to another one, indicating that a change in the system state occurred. This may means that an entity changed its value or an event happened, for instance. In this paper, authors consider that a notification represent a link between *Rules* and *FBEs*. These links may have two meanings, according to the link direction. A notification from a *FBE* to a *Rule* (i.e. *FBE* → *Rule*) describes a given precondition for that *Rule* related to the indicated *Attribute* of the *FBE*. A logical expression from a defined algebra must be assigned over the link to describe the logical condition. Figure 2 (c) illustrates this type of link. On the other hand, a notification from a *Rule* to a *FBE* (i.e. *Rule* → *FBE*) describes that the *Rule* invokes a function from a *Method* of an *FBE*. A reference to the *Action* is to be written over the link as illustrated in Figure 2 (d).

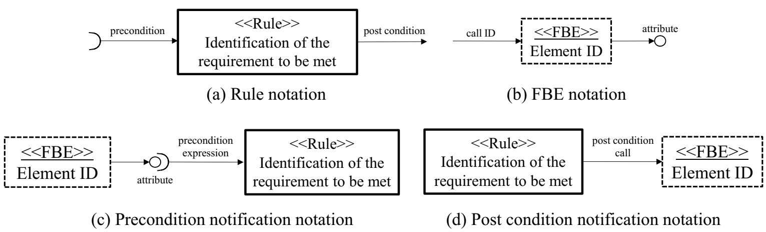

Figure 2. Notation used for drawing systems requirements models.

3.2. NOP Based Requirements Modelling

From the primitives established in the previous section, authors propose to construct the system requirements specification in the form of a system requirements model. This model may include a single or multiple diagrams using the NOP notation. The input for the modelling process is the system requirements sentences. A general view of the adopted modelling technique follows.

For each requirement statement in the system requirements specification:

1. *To analyse the requirement sentence aiming at:*
   i. *Identifying the functional or non-functional request in the requirement.*
   ii. *Identifying the Conditions for the functional or non-functional request.*
   iii. *Identifying the Attributes involved in the Conditions.*

iv. *Identifying the Actions for the functional or non-functional request*
v. *Identifying the functions related to Methods instigated in the Actions.*
vi. *Identifying the FBEs related to the Attributes for the request.*
vii. *Identifying the FBEs related to the Methods indicated by the request.*

2. *To create a Rule for every request identified in step 1.*
3. *To create a FBE for every entity identified in step 1.*
4. *To create links (i.e. notifications between Rules and FBEs according to the Conditions and Actions related to rules) identified in step 1*
5. *To merge FBEs and Rules with analogous FBEs and Rules previously created.*

Step 1 involves analysing every requirement sentence in order to identify the specific request inside the stated requirement. Commonly, it should exist only one request per requirement. However, sentences in natural language expressing requirements for a system may explicitly or implicitly refer to more than one request. Additionally, the request may specify an intended action to be carried out by the system (referred to as functional request) or it may specify constraints, properties or conditions for the system (referred to as non-functional requests). In this step, the elements related to the conditions and actions of the request are also identified considering the references to aspects, objects, devices or interfaces with the external elements. Steps from 2 to 4 are related to the construction of the requirements model from the elements identified in step 1, i.e. the identified *Rules*, *FBEs* and links. Step 5, particularly, concerns integrating models constructed from each system requirement. This may involve merging *Rules* and *FBEs* and reconnecting links between them.

To illustrate the proposed modelling technique it is taken into account the following example of system requirement statement: "The system shall activate the fire alarm when the temperature sensor indicates more than 60°C in the room". Analysing this requirement sentence, the system analyst can identify "activate the fire alarm" as the stated functional request. The condition of the *Rule* for that request is "temperature more than 60°C" and the element associated to this condition is "temperature sensor". The *FBE* temperature sensor shall expose an *Attribute* that contains the current temperature in the room. Finally, the element responsible for the function "activate" is the "Fire Alarm" instigated by the action of the rule. Thus, following the steps 2, 3 and 4 of the proposed technique, the resulting model is presented in Figure 3.

Figure 3. System requirement model example.

4. Case Study: Access Security System

This section presents the modelling example of an "Access Security System" extracted from the INCOSE SE Handbook v3.2 [3]. This study is based on six system requirements that specify the intended functional and non-functional characteristics of the system.

4.1 Case description

According to the SS11 Stakeholder Requirement presented in [3], the secure areas (i.e. rooms that have limited access) are to be protected by two independent security checks. One of them is based upon an employee ID and the other one is based upon biometric data. The time between the two independent security checks shall not exceed a configurable period. The user is allowed three attempts at biometric and/or card identification before access is completely disabled. Any denied access attempt is to be sent to the administrator.

The system requirements statements are:

- *SS11 – a: Secure areas shall be protected by security check based upon employee ID.*
- *SS11 – b: Secure areas shall be protected by a second independent security check based upon biometric data.*
- *SS11 – c: The time between the two independent security checks shall not exceed a configurable period.*
- *SS11 – d: The user shall be allowed three attempts at biometric identification.*
- *SS11 – e: The user shall be allowed three attempts at card identification.*
- *SS11 – f: Any denied access attempt shall be sent to the administrator.*

4.2. NOP-Based Requirements Models

This section applies the proposed technique showing the main phases of the Access Security System requirements modelling.

Requirement SS11-a:

This requirement indicates that the system shall "protect secure areas" what means that the system shall meet two requests: enabling and disabling access to the secure area. As consequence, the system will have to command an element (e.g. a blocker) that carry out these two actions. This requirement also states that a "security check based upon employee ID" will provide the condition to enable or disable access to secure areas. The identified attribute for this condition is the "employee ID" read from an external element (i.e. an ID card reader). Figure 4 shows the model of this requirement where three *Rules* and two *FBEs* are identified.

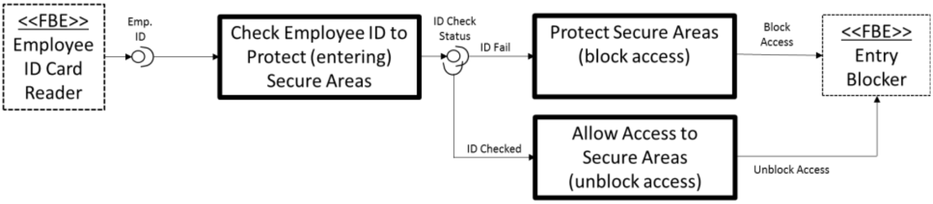

Figure 4. Model of the SS11-a requirement.

Requirement SS11-b:

This requirement is similar to SS11-a and its model will also include two *FBEs* and three *Rules*. The first *FBE* represents the *Biometric Reader* element and the second the *Entry Blocker*. The last is the same *FBE* indicated in the model of SS11-a because the *Entry Blocker* will be obviously the same. The first *Rule* will represent request for checking the employee biometric. The two other *Rules* represent the request to enable and disable access to the secure area as modelled to SS11-a.

Because of their inter-relationship, SS11-a and SS11-b models can be integrated, as illustrated in Figure 5. The *Rule* "Protect Secure Areas" receives a <<disjunction>> operator to indicate that any or both conditions enable this *Rule*. The *Rule* "Allow Access" in turn receives a <<conjunction>> operator to indicate that both conditions must be satisfied to enable this rule.

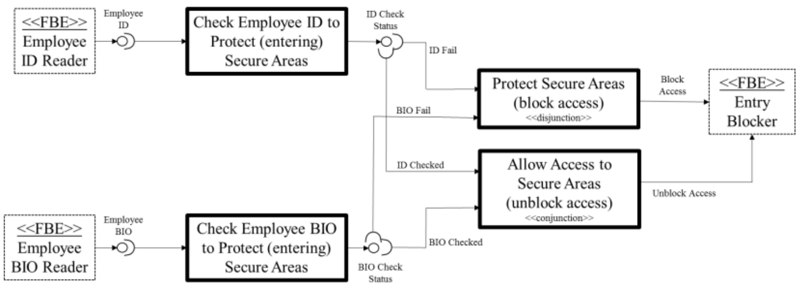

Figure 5. Model of SS11-a and SS11-b requirements.

Requirement SS11-c:

This requirement adds a new time constraint with respect the secure checking of ID and BIO. It leads to a new functional request involving checking the elapsed time between the ID and BIO secure checking. It also sets new conditions for enabling or disabling access and establishes two new *Attributes* for the current system time (*Cur_Time*) and system configured time period (*Conf.Period*). This way a new *Rule* (*Check Elapsed Time*) and two new *FBEs* (*System Clock and System Config*) are inserted in the model as illustrated in **Figure 6**.

Requirement SS11-d and Requirement SS11-e:

These requirements are very similar once both limit the number of user attempts. The request in both requirements can be merged in a single request that counts the number of ID and BIO checking attempts. A new *FBE* (*User Attempts Counter*) is created and new conditions about the status of the user attempts are inserted for the *Rules* that represent the request to enable and disable access to the secure area as illustrated in **Figure 6**.

Requirement SS11-f:

This last requirement defines a new functional request for notifying the administrator when a user access attempt is denied. This leads to a new *Rule* to represent this notification. However, because the conditions for that *Rule* are identical to those of the "*Protect Secure Areas*" *Rule*, they can me merged and a new link is create to command the notification action by the *Administrator Interface FBE*. Figure 6 illustrates the final system requirements model for the considered example.

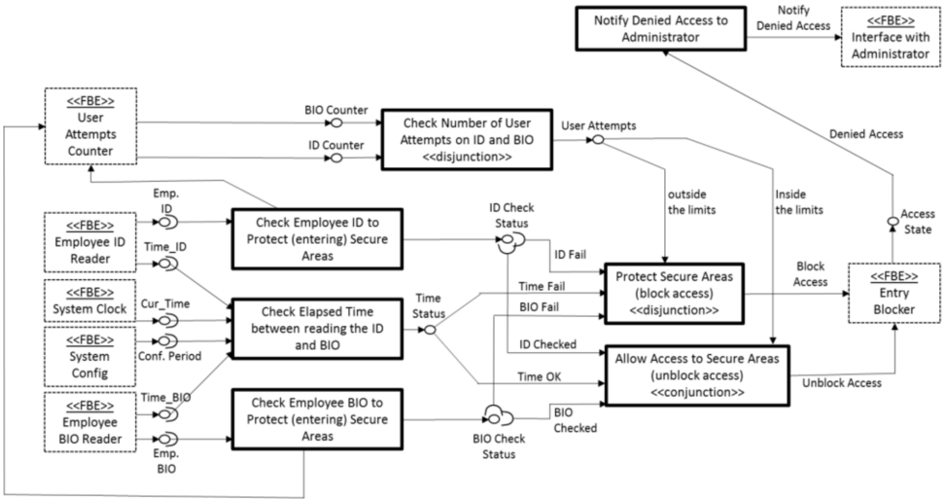

Figure 6. Final system requirements model.

5. Conclusions and Future Works

This paper proposed a novel approach for systems requirements modelling that makes use of concepts and the notation of the previously developed Notification Oriented Paradigm (NOP). NOP has been successfully applied for modelling, programming, and executing software applications based upon three fundamentals primitives: *Rules*, *FBEs*, and notifications. Based on these concepts, this paper presented a technique for constructing a graphical model of the expressed system requirements. An example of an access security system illustrated the proposed approach.

The presented approach uses a graphical notation, thus facilitating the analysis of the requirements and identifying hidden knowledge. Additionally, this approach makes explicit the logical dependencies (*Rules* with their conditions and actions) between the requirements through linked and shared *Attributes* and *Methods* of involved elements (*FBEs*). These characteristics allow modelling the whole set of requirements taking into account their inter-relationships. In the context of larger scaled systems, the proposed approach should provide means and tools for semi-automatically generating systems requirements models.

However, the proposed approach does not yet take into account the meaning behind the requirements in order to identify hidden semantics inter-relationships. Indeed, this semantics is generally domain-dependent and thus related to some deep and implicit knowledge of the related skills of the stakeholders. Authors' working in progress explore using ontologies as a suitable solution for expressing these aspects of requirements together with the modelling approach presented in this paper.

Acknowledgement

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Support System Design for Remote Area Surveillance and Protection Requirements

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Abstract. The Australian mainland has 35,876 km of coastline, and an additional 23,859 km of island coastline. The persistence of illegal, unreported and unregulated fishing has been identified as a major factor contributing to the overexploitation of marine resources worldwide. Unfortunately, this vast area requires a great deal of resources and costs hundreds of million dollars to protect. Due to decisions at different times, the patrol boat bases are located at the east side of Australia while most illegal activities are at the north west, which is located a vast distance from where the asset is. Instead of piecemeal development in the past, the current situation has called for a model-based design methodology for the support system design. This paper reviews methodologies commonly used in service systems design and outlines a system model that captures elements of the support system and improves the processes of developing a viable solution to the problem.

Keywords. Border protection, offshore patrolling, support system for remote areas operations, coastal security

Introduction

Illegal fishing vessels operating in the Tropical Waters of Australia take a great deal of resources to combat, and introduce disease and marine pests into the environment [1]. Of further concern is an ever-growing need to protect against illegal immigration, brought about by the opportunistic behaviour of foreign nationals who gain great financial benefit from people smuggling operations. Both threats increased significantly and initiatives have been taken at national, regional and global levels to protect Australia's national interests at sea [2].

People smuggling operations have been prevalent for many years [3]. To conquer these illegal activities, the Royal Australian Navy (RAN) was directed to intercept and board Suspected Illegal Entry Vessels – that is, boats that were suspected of carrying people seeking to come to Australia without a visa – when they entered Australia's contiguous zone (24 nautical miles from the Australian coast).

The majority of patrolling to combat illegal fishing is performed by the RAN Armidale Class Patrol Boats (ACPB). The RAN also provides support to the BFA (formally known as the Australian Customs and Border Protection Service), in the apprehension of people smuggling operations, whose primary resource are the Cape Class Patrol Boats (CCPB).

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However, the cost of protecting Australia's vast territorial interests from illegal foreign fishing annually was more than $500 million per year [4]. The effort required no less than 10 Federal Government agencies working together. Moreover, the RAN ACPB assets are home-based in either Cairns or Darwin, and Customs CCPB vessels are all home-based in Darwin. As a result, these valuable assets are located a vast distance from where the majority of illegal Foreign Fishing Vessels (FFV) operate, and where Australia is most vulnerable to illegal boat incursions, along the North-West coast of the country, and among the many shoals, reefs and islands in this vicinity. A better support system is urgently required for this type of critical capabilities.

The principles of service system design have been studied for some time. Stevenson [5] concluded an exploratory study with five critical roles of services: to provide continuity, to allow for expansion, to provide expertise, to improve cost efficiency, and to reduce risk. However, the ad hoc development approach used in the past should be changed to ensure a holistic approach. The concept of product-service system (PSS) represents a novel business development but it requires a new methodology to support ideation and preliminary design [6].

This research paper applies an enterprise model to design a viable support solution for improving patrols along the North-Western Australian coastline. The requirements of the new Patrol Boat Support Facility (PBSF) are expressed in terms of three key elements in the enterprise model, i.e. people, process and product, and their interaction within the specific operating environment. It is envisaged that the establishment of such a facility could be utilised by BFA and other government departments in support of coastal patrols for illegal immigration and to combat against people smuggling operations, as well as illegal fishing in the area.

1. Literature Review

Classical services and maintenance plans are designed on the principle that mean time between failures is a constant and hence the focus is to replace components before it is expected to fail. Typically, service activities including inspection, adjustment and replacement are scheduled in fixed intervals [7]. Due to multifaceted relationship between operating context and characteristics inherent in the complex system, these intervals may not be optimised. Many services decisions on assets are therefore made on rules of thumbs rather than using analysed system performance data [8].

A service system often involves active interaction from several independent, collaborating enterprises. Several research attempts have been made to understand how enterprise architecture methodology should be applied in engineering services. Chattopadhyay and Mo [9] modelled a global engineering services company as a three-column progression process that was centred on human engineering effort. Ivanovic et al [10] investigated system architecture investments for aligning with (current and future) business goals. They found that a systematic design methodology should be used to develop well defined policy and processes across the organisational boundaries and the changes should be implemented in all enterprises concerned during the process.

Cohen et al [11] observed that in product/service bundling, products may be owned by a consumer, a customer, a leasing company or a manufacturing service provider. They characterised business models associated with after-sales service as disposal, ad-hoc, warranty, lease, cost-plus, performance based, power-by-the-hour. Boviard [12] observed an increasing interest in public-private partnerships where government was the customer who might or might not own the asset being supported. Purchase et al [13] discuss the individual, organisational and inter-organisational challenges faced in the move from a product to a service orientation in a public-private partnership setting, highlighting a need for both sides to develop new attitudes and competencies and viewing the working arrangements as a complex adaptive system.

The concept of "product-service system" (PSS) was introduced in 2002 meaning to design market well-matched service for itemized product and indicates that collaboration between team members of teams working within different locations and professions should come together [14]. Lightfoot et al [15] investigated the strategy of servitization, which aims to improve the innovation ability of an organisation to improve joint value through a shift from selling product to selling service system with their product. Sampson [16] explained the Unified Service Theory (UST) that standardizes the customer feedback of the service design methodology. These concepts are further amalgamated under Complex Engineering Service, which describes systems that aims to deliver value to the customer through a system of people, process, asset and technology and the interaction between them rather than the function of the individual components themselves [17]. Irrespective of its widespread applicability, the service business still suffers from difficulty of integrating partners in the PSS virtual enterprise [18].

The rationale to use enterprise engineering methodologies to guide service system transition is to minimize enterprise design modifications and associated rework of the system governing information and material flows [19]. Any unplanned change to the enterprise is an impact of uncertainty to enterprise performances. The support system architecture serves as a framework for consolidating existing knowledge of the service system as well as an instrument for examining future requirements in such a system in a simulated environment and developing plans for achieving the expected future state. Fizzanty et al [20] identified issues in supply chain sustainability and developed a framework for guiding implementation that established commitment among stakeholders and lowered the risk of the system. However, these service system designs were compromised by the commercial reality. For support of a mission critical operation like ACPB, a holistic approach is required.

2. Enterprise reference model

This paper uses an enterprise modelling approach to map out components of the enterprise under which the product and related services are changed [21]. The enterprise system for service and support systems has three interacting components operating within a business environment (Figure 1). The system captures the requirements of three important elements: People, Process and Product (3P), and the interactions among these elements. These elements will operate within the Environment (E). Using the 3PE model, existing facilities and resources can be re-grouped to relevant sub-systems and demand for new resources can be incorporated.

The primary objective of the PBSF project is to provide the Australian Defence Force (ADF) and BFA with improved surveillance capability by providing a platform for surveillance activities in closer proximity to known areas of illegal activities, including illegal fishing, people smuggling and illegal immigration activities. Extending from this, a secondary objective is to provide the ADF with enhanced capability for supporting other operations within the Australian Economic Exclusion

Zone (EEZ) along the Western Australian coast, including but not limited to salvage operations, Search and Rescue operations or special operations such as escort tasking.

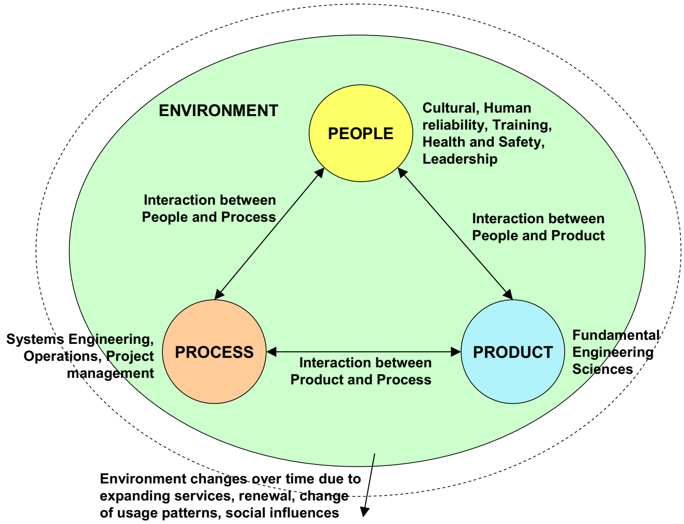

Figure 1. Product, Process, People, Environment (3PE) model.

2.1. People

The People element comprises a large number of stakeholders. Some of the key stakeholders are described below.

- **Defence Materiel Organisation (DMO)** – Responsible for acquisition, and the management of capital equipment and systems and through life support of materiel on behalf of the Australian Defence Force.
- **Principle Contractor** – Responsible for project management, coordination of work, cost and schedule management and subcontractor negotiation and management.
- **Subcontractors** – Responsible to the principle contractor for completion of contracted work including (a) Environmental Impact Assessment and reporting; (b) Dredging; (c) Excavation; (d) Construction; and (e) Test and Evaluation (T&E) support.
- **Maritime Commander Australia** – Responsible for RAN fleet operations in Australia.
- **Commissioner Border Force Australia** – Responsible for BFA security operations.
- **Commander Australian Patrol Boat Forces** – Responsible for direction and control of RAN Patrol Boat operations.
- **Premier Western Australia** – Responsible to Western Australians for management of state assets including the protection of marine life and border protection, and ensuring guidelines associated with dredging operations are adhered to.

- **The Minister for Defence** – Responsible to all Australians for the implementation and management of defence assets and defence operations, including Intelligence and Security, International Policy and Force structure.
- **The Minister for Agriculture** – Responsible to all Australians for the management of biosecurity and the protection of regional areas in relation to quarantine services.
- **The Minister for Immigration and Border Protection** – Responsible to all Australians for the management of immigration and border control.
- **Austal Australia** – Responsible for in-service support of the BFA Cape Class Patrol Boats.
- **Defence Maritime Services Australia** – Responsible for in-service support of the RAN Armidale Class Patrol Boats.

It is also proposed to construct housing for 17 accompanied Officers, 5 Senior Sailors and 30 Junior Sailors, as well as single accommodation for all ranks in separate buildings, and incorporate a pool and bar at the location.

2.2. Process

All artefacts defining the project shall be maintained under configuration control. All subsequent schedule changes are processed by way of a change request process. Any contract milestone change requires the capability provider and DMO approval.

Data management is the responsibility of the Integrated Logistics Support (ILS) team. The processes and procedures are established by the QP. The process of data management is structured so that all deliverable data will be supplied in accordance with the contractually defined Contract Deliverables Requirement List (CDRL) and Software Deliverable Requirements List (SDRL). The content and quality will be in accordance with the respective Data Item Descriptions (DID) referenced in the contract, utilising approved and established processes and systems for data management.

The risk management process shall be controlled through existing company procedures and shall be defined in a separate Risk Management Plan (RMP), to ensure that objectives are met without undesirable consequences, as a result of threats to the projects technical parameters, costs or schedule. Updates/status of the risk management process shall be provided monthly by monthly progress reports.

An Integrated Product Team (IPT) shall be set up to maintain responsibility for the Subcontract Management function. The IPT shall professionally manage each subcontractor to ensure that all procured hardware, software, data and services meet or exceed customer and company technical, schedule, cost, and quality requirements.

The Supplier Management representative to the IPT is responsible for adherence to policies and procedures, pertinent to the project. Consistent application of current disciplined procurement practices throughout the contract period of performance shall be maintained. These processes and procedures are flexible enough to allow for variations necessary to meet the requirements of the program.

2.3. Product

The scope of the project is to construct a new support base between Exmouth and the Naval Communications. The patrol boats the product in the system. To ensure success, a risk assessment and environmental assessment of the area will be pursued including dredging operations to support sufficient berthing facilities for 8 patrol boats with a draught of no more than 3 metres, and the construction of buildings, including an Administration building, Stores and Maintenance facility, Fuel storage, Undercover berthing for 2 vessels, and additional external wharf area for a further 6 vessels.

A summary of spending for the project is provided in Table 1. This table expresses costs in real terms, as well as applying a 10% PV cost to each activity, taking into account the year that each activity will finish, over the course of a five year lifecycle.

Table 1. Summary of costs.

Cost tegory	PV Not Applied		PV Applied	
	TOTAL $	Percent	TOTAL $	Percent
EIA	$5,836.98	0.01%	$5,306.35	0.02%
Construction	$19,250,898.00	45.25%	$11,953,293.06	40.83%
Dredging	$287,369.23	0.68%	$237,495.23	0.81%
Excavation	$21,462,000.00	50.44%	$16,124,718.26	55.08%
Engineering	$540,000.00	1.27%	$335,297.51	1.15%
T&E	$150,000.00	0.35%	$93,138.20	0.32%
STW	$350,000.00	0.82%	$217,322.46	0.74%
Contingency	$500,000.00	1.18%	$310,460.66	1.06%
Grand Total	$42,546,104.21	100.00%	$29,277,031.73	100.00%

2.4. People – Process Interaction

From the outset, a baseline shall be struck to ensure progress is able to be monitored on a regular basis. The Project Manager (PM) shall be responsible for schedule updates, utilising the latest information and incorporating changes as necessary. The PM will establish a management reserve that will be held within the project budget, and will be used to fund unexpected management and/or technical problems or emergencies.

Information flows necessary to achieve responsible project communications will be driven from the formal and informal communications needs of the Project teams. The processes for formal communications between the project lead team and external organisations will be defined by the contract, with the contracts manager authorised to initiate and respond to the formal communications of the customer including contract changes.

2.5. Product – Process Interaction

The formal design authorised contractor action communications are established in the SEMP. From the SEMP, the budget can be established. Budget management shall be maintained utilising existing policy, directives, procedures, and processes.

Cost and schedule reporting will be maintained via a system where work authorization, planning and scheduling, budgeting, accounting, performance management, variance analysis, estimates at completion, and reporting are integrated into a single closed-loop system.

A recognised database for financial management, technical planning, performance review, change control, and program management, shall be employed throughout the project.

Of the eight Patrol boats berthed at the facility, at least 5 boats should be operationally ready to deploy at any time for surveillance, salvage, search and rescue or special operations. Both RAN ACPB and BFA CCPB shall be rotated in line with current crew rotational schedules. Any long term maintenance or refit programs should not be conducted whilst alongside at the PBSF.

2.6. Product – People Interaction

The establishment of a PBSF in the Exmouth area of Western Australia would provide infrastructure capable of supporting both Customs Cape Class and RAN Armidale Class Patrol Boats, which would be able to berth at the facility on a rotational basis. The proposed facility will allow for up to 8 patrol boats to be berthed at any one time, with two of the vessels housed in a purpose built undercover maintenance facility.

Accessibility to existing in-service support contractor – AUSTAL Australia, who currently have the support contract with BFA for the CCPB, are home-based at the Henderson shipyard in Perth, the development of this facility will provide AUSTAL with more accessibility to CCPB vessels who are on station at the PBSF, as well as providing BFA with the ability to sail to Perth for maintenance on completion of a rotation at the facility

2.7. Environment

The proposed location of the facility is approximately 7 km South of NAVCOMMSTA Harold E Holt, and 6 km to the North of the township of Exmouth (the green arrow in Figure 2).

In order to establish a facility at this location, the site location will need to be dredged to a depth of 4 metres, in order to allow the construction of a wharf facility for the berthing of both RAN ACPB and BFA CCPB vessels, and for the construction of an undercover maintenance building in which vessels will be able to berth for extended maintenance activities, whilst out of the weather.

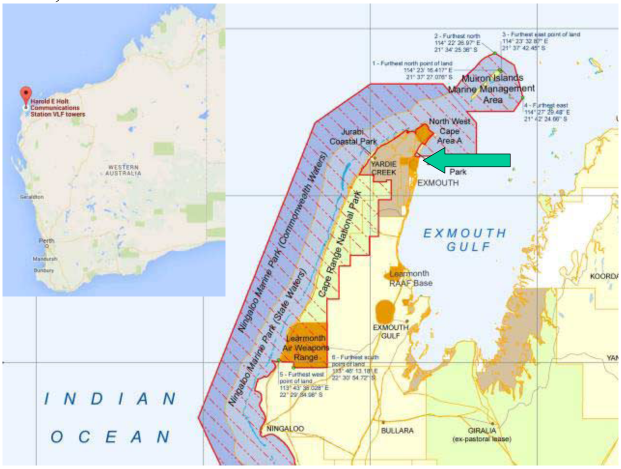

Figure 2. Location of proposed facility.

In addition the facility will provide both the RAN and BFA to conduct routine surveillance operations, search and rescue missions, salvage operations and support operations for other government and non-government organisations along the Western Australian coast within the Australian Economic Exclusion Zone (EEZ).

2.7.1. Environmental and Regulatory

The environment impact assessment shall be conducted in strict accordance with the Environmental Assessment Guidelines provided by the Environmental Protection Authority (EPA) of Western Australia, as prescribed under Part IV of the Environmental Protection Act 1986.

The Contractor will be compelled to protect the environment throughout the construction phase of the project. Storm-water management techniques will be used to prevent erosion and avoid the discharge of storm water into the ocean. Disposal of waste shall be conducted in accordance with the National Assessment Guidelines for Dredging (NAGD). Of high consideration shall be the need to ensure waste prevention, with an audit undertaken prior to commencing any dredging operations in order to identify opportunities for the prevention and minimisation of pollution and contamination of the marine environment. Dust control measures will be implemented to minimize air pollution during site preparation and construction.

The storage of diesel at the proposed facility may pose a risk for air quality management, and therefore costing will include state of the art anti-pollution measures to ensure any risk to the environment is minimised.

2.7.2. Architecture Compliance Statement

The specific operation of business architecture products will be compliant with the information and technology embodied in the Defence Architecture Framework (DAF). The primary mission of the PBSF is to provide an enhanced surveillance and protection capability in the Defence of Australian borders, by ensuring those vessels and crews tasked with the protection of the Australian mainland are afforded more accessibility to foreign entry, whether it be fishing vessels or people smuggling operations.

2.7.3. Operational Constraints

The operation of APCB has many constraints to observe. Hazards brought about by the use of electronic and hazardous Radio Frequency (RF) equipment, which can have adverse effects to personnel health, as well as explosive ordnance and flammable materials, will be minimised by the location of HF equipment at NAVCOMMSTA Harold E Holt, and the mounting of VHF/UHF antennas on the roof of the main administration building.

Personnel security, physical security and system security must be considered through vigilant application of Defence Security Manual (DSM) and the Information Security Manual (ISM). Physical security of the site shall be maintained during construction, with only those personnel necessary for site construction permitted to enter the area.

In all scenarios, the support facility maintenance staff shall be required to ensure that at least 5 patrol boats are operationally ready for deployment.

Maintenance staff should ensure all weapons, communications and mechanical systems are functioning correctly, and that all planned maintenance activities are carried out in accordance with standard schedules.

At present patrol boats must travel vast distances in order to adequately patrol along the north Western Australian coast. Such patrols cost the Australian government a great deal in resources such as fuel costs, berthing costs in remote localities and the need to replenish supplies.

The implementation of a new support base on the NW Cape would reduce costs, as berthing arrangements on a defence facility would not incur expensive fees, fuel costs would incur charges for freight, as is passed on to boats berthing at remote localities, however as the new PBSF design includes fuel storage, the costs of refuelling would be greatly diminished, and freight costs would be lessened with the ability to store parts, components and consumables including victuals at the support base.

As it is envisaged that patrol boats would continue normal rotational schedules, it is feasible that patrol boat operations at the new facility would further decrease the burden on ships crews and families, due to the fact that patrol boats would not need to be located at the base for extended periods. The current rotational schedule of crews would mean that a ships company would only need to be stationed at the new facility for 6 weeks in every 20 months of operation.

3. Conclusion

This paper does not purport to propose a new solution to a problem affecting Australian Customs and Naval personnel, but rather a viable solution to improving existing procedures, by enhancing coverage of Australia's most vulnerable section of coastline. The benefits of this project include:

- Reduced costs of refuelling – Due to the ability to store fuel at the facility, and not replenish at a remote locality refuelling wharf
- Reduced operational costs – Due to less transit time required from base to area of operations
- Increased presence in the North-West area – Due to a more localised presence, and shorter distances from home base
- Increased employment opportunities in the area – New on-site personnel housing, base facilities and recreational infrastructure and ongoing employment opportunities in nearby Exmouth

The use of enterprise model 3PE to incorporate different system components into different sub-systems provides a structural implementation of the system with thorough systems engineering principles, including sufficient consideration of the support environment, an understanding of what a service is, and the deliverables required in order to provide a successful service and a comprehensive understanding of service frameworks. The effects of supply chain and logistics in the support solution have been considered thoroughly and included in the design of the facility. Maintenance, both planned and unplanned, are key to the principle functions of the facility, and have been included in all documentation, while Service and Support operations are vital for the implementation of the support facility proposed by this paper.

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An Application Domain-Based Taxonomy for IoT Sensors

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Abstract. If we look at the Internet of Things (IoT) from a viewpoint that comprises higher levels of abstraction, we will see that the IoT generated data can actually be transformed into more complex information, which would in turn facilitate the lives of human users. Because sensors have different purposes and measure different phenomena, it is necessary to know them and their different areas and domains of application so we can make a better use of their potential. This paper presents the identification and categorization of the main sensors used these days to build IoT applications, arranged in a taxonomy of application domains and sensor measurement types. To this purpose, we review the literature in order to identify IoT solutions, areas and domains of application and the main sensor types employed in these solutions. We hope this taxonomy can provide IoT designers, developers, and researchers with a snapshot of how sensors are currently used in the IoT application domains. Knowing the source devices is a key strategy to provide publication, discovery, sharing, reuse and integration of data/information within the IoT. We believe identifying and categorizing those sensors could be the first step to creating in the future a common communication model, which could be instantiated from each environmental context on the IoT.

Keywords. Internet of Things, IoT, Application Domain, Sensors, Taxonomy

Introduction

Internet of Things (IoT) is the term used to describe the vision in which "things" are interconnected and are capable of transmitting and receiving data through the Internet. The IoT allows "things", i.e., everyday objects, to perceive and to interact with the world, performing tasks and communicating with each other to share information and coordinate decisions [1]. Physical phenomena information is perceived by sensors, transmitted, aggregated, analyzed and used in the digital world, and as well as in the physical world by means of actuators that generate actions over the environment [2].

The integration of objects in the Internet allows new forms of management of the "moving parts" of businesses, since the state of vehicles, people, equipment and products is available in real-time for monitoring and controlling. IoT objects could

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embed sensors and actuators in order to be able to autonomously respond to situations according to defined rules [3], under various scenarios. Thereby, we can envisage the IoT potential through the variety of applications and services that it enables and the sectors that can be exploited.

A major element that produces inputs used by IoT applications are sensors, which provide measures of people, objects and the environment, in real-time or within certain time intervals, according to the application. A report generated by IDC [4] states that in the first half of 2014 the world had about 20 billion objects which contained embedded sensors and communicated to each other through the Internet. It also estimated that in circa 2020 this number would be of approximately 30 billion devices.

Sensors have different purposes since they provide different types of measures of: (i) objects, such as speed, fuel level and tire pressure of vehicles; (ii) the environment, as the temperature of a room and the amount of CO2 on a busy street; and (iii) people, as the amount of oxygen and glucose present in a blood sample. The combination of sensors serving different purposes allows the creation of complex services [5], for example, a system for agriculture, which combines position and humidity sensors to control the level of water in the fields [6]. However, the wide variety of existing sensors and its constant growth can hamper the discovery and selection of the most appropriate sensor type for each application domain.

In this paper, we propose a taxonomy to categorize the types of sensors used nowadays in different IoT application domains. To this end, we analyzed several IoT-based initiatives in order to identify the main IoT application domains and the sensor types currently used in each one of them. First, we present a table of summarized information on sensors and finally, the proposed IoT-based taxonomy for sensors.

The remainder of this paper is organized as follows. In section 1, we review the IoT application domains. In section 2, we present a survey on the IoT sensor types. In section 3, we present the related works. In section 4, we present the proposed taxonomy; finally, in section 5 we provide the closing remarks of this work.

1. IoT Application Domains

The IoT is becoming more and more used in several areas of activity since it enables the creation of a myriad of applications and services. By means of the use of large volume and variety of data produced by networked devices, the IoT fosters the generation of new applications [7] which can, for example, monitor the environment and climate, trigger actions and events, provide subsidies for making decisions and improve the quality of life by automating everyday tasks. Some of the IoT application domains are Smart City, Industry, and Health and Welfare [8].

The Smart City domain comprises IoT-based services applied to different areas of urban settings. Smart City applications envisage the best use of public resources, improvement of the quality of services provided to people, and reduction of operating costs of public administration [7]. Combining Smart City applications with IoT-based services allow the establishment and improvement of services focused on: (i) mobility and intelligent tourism, providing, for example, information about the state of roads, occupation of parking lots and the history of tourist attractions; (ii) smart grids, allowing better management of the network through new information on energy consumption; (iii) intelligent building, allowing new forms of residential automation, and infrastructures for monitoring and controlling; and (iv) public safety and environmental monitoring, facilitating the management of environmental disasters and strengthening the security of buildings open to the public [8].

IoT-based services are also used in the industry domain, such as in agricultural activities, factories and issues of logistics of resources and products. In agriculture, IoT applications are used to perform the monitoring of soil moisture [6] and the conditions of the plants, control microclimate conditions and monitor weather conditions that can damage the crops [9]. In the factories, we can find applications for monitoring of pollutant gases [10], locating employees [11] and improving the manufacturing process [12]. Moreover, in logistics issues, IoT-based services can be applied to the improvement of the processes involved in supply chains [13].

In the domain of Health and Wellness, we find IoT applications used for monitoring and diagnosing of patients, and for managing of people and medical resources. IoT-based services applied to the health domain enable the creation of applications to remotely and continuously monitor the vital signs of patients in order to improve medical care [14]. Besides, they ease the diagnosis by providing health indicators for patients, and enable the identification and tracking of equipment in a medical institution [9].

The diversity of applications and services based on the use, sharing and combination of data generated on the IoT shows us the need to know and classify the sources of data and information on the IoT. Since sensors are the main data generating devices in the IoT, we present in the next section a review of them in such a context.

2. IoT Sensor Types

Sensors are largely responsible for the generation of data consumed by applications in the IoT. In general, sensors are devices composed of components that are responsible for the perception and conversion of collected data, being able to obtain measurements on several phenomena, providing new inputs to be combined and analyzed by IoT applications [16]. One of the most important aspects when choosing a sensor is the kind of phenomenon that it is able to measure [5], and the target phenomenon is closely connected with the service the solution designer wants to provide.

Displacement and position sensors are present in diverse applications in the IoT. Measures related to movement, such as vibration, inertia, acceleration, rotation and speed are useful in applications related to traffic management [2], indoor location [11], and tracking of transport fleets to industry [9]. Moreover, sensors that provide measurements related to positioning of objects and people, such as presence, proximity, orientation and location are present in applications related to vehicle location [17], indoor location [18], intelligent parking system [19], and management of laboratories in educational institutions [20].

Other types of sensors are those that monitor the environment. For example, temperature sensors are used in homes for heating systems [21], ventilation and air conditioning (HVAC) [22] or, when coupled with gas sensors, in fire detection systems and in intelligent agriculture [23, 24]. Gas sensors may be used for gas detection in smart city applications to measure urban pollution [2]. Acoustic sensors are used for environmental conservation in applications for monitoring bird populations and illegal logging [2]. Weather sensors are used in applications related to irrigation and intelligent agriculture [2, 6, 24]. Applications for the medical domain also make use of sensors for measuring temperature, humidity and for detection of toxic agents (gas) in services for monitoring of well-being and health of a patient in their own home [25]. In industry, radiation sensors are used to detect levels of radiation in nuclear power plants, gas sensors are used to identify leaks in industrial environments, and fluid sensors are used to detect leaks in data centers and data warehouses, preventing damage and losses resulting from these leaks [9].

We can also find sensors that measure the mass of a body or the effects of phenomena on that body. These types of sensors assist in the formation of smart cities. There are, for example, applications to monitor the flow of water in water pumps or rivers [2] and to measure the mass of an athlete by the pressure exerted on a scale, in the smart health domain [26]. Furthermore, there are also sensors that measure the force, load and tension being used in monitoring of infrastructures, such as buildings and bridges [2].

Focused on health and medical care, we can also find sensors to measure chemical and physical phenomena of the human body. These sensors are used to measure heart rate (electrocardiogram), muscle electrical activity (electromyography), blood pressure, cholesterol level, amount of oxygen and sugar in the blood, body temperature and SpO2, in services for local or remote monitoring of patients [27-29, 14, 9]. In addition to monitoring the health of patients, there are sensors applied to medical domain used to diagnose the health condition of patients [9] and in the management of medical institutions, by monitoring and tracking of patients, staff and medical equipment [30].

Some technologies commonly used by IoT applications and services, in a complementary way or as the main data sources, are the Radio Frequency Identification (RFID) and the Global Positioning System (GPS). RFID provides identification of people and objects, and is used for various purposes such as tracking packages [17] or access control in a building. Besides, RFID is part of the first definition of the IoT, in which "things" were simple identifiable RFID objects [31]. GPS has the purpose of identifying the current location of an object. Various applications use GPS, such as the ones that track transport facilities [32] or identify suitable routes to a given destination.

It is important to remark that the choice of sensor does not rely only on the types of measures provided by them. Features like accuracy, repeatability, operating range relative to the input signal, reading fluctuations (generated by internal or external noise), resolution, and selectivity also affect the choice of which sensors to use [5]. Since this work focuses on the relation between sensor types and IoT application domains, no further discussion will be taken about these other sensor features. We have chosen to let this matter to be addressed in future works.

As we can notice, this short overview of sensors and the relation between them and their possible fields of application becomes a key aspect for discovery, sharing, reuse and integration of data in the current IoT.

3. Related Works

At this moment, in the literature, we can find works that classify and provide descriptions and examples of applications related to a particular sensor type [2, 5, 15, 33] or propose taxonomies related to general and specific aspects of the IoT. Referring to the general aspects of the IoT, there are taxonomies related to concepts of connected objects [34], deployment scenarios [35] and base and architectural technologies [8]. In relation to the specific aspects, we can find taxonomies for use cases focused on the health domain [36], security and privacy [37, 38, 39], and sensor measurement [40].

The works in [2, 5, 15, 33] present summarized classifications of sensors by giving, in general, practical examples and applications, and providing overviews of the sensors used in the IoT. We consider these works as a first step in creating a more elaborate categorization of sensors, which provides information about possible areas of use and application domains for sensors.

In contrast to [40], which provides a taxonomy for categorizing sensors using a specific set of measures, in this work we propose a taxonomy for IoT sensors based on the analysis of works and applications identified in the literature, in order to explain and characterize sensors and application domains as they are used now into the IoT.

4. Proposed Taxonomy

A taxonomic classification allows the organization of a knowledge domain, in order to improve the access and understanding of information. A taxonomy for IoT sensors helps us understand how certain types of sensors are combined and used in different application domains. To develop a taxonomy for IoT sensors, we have conducted a survey on studies related to the IoT into the following databases: Web of Science, IEEE Xplore, ACM, ScienceDirect, and Scopus. From the data collected, we have detected the following classification of sensors identified by type and subtype, as shown in Table 1.

Table 1. IoT sensor types and subtypes.

Type	**Motion**	**Position**	**Environment**	**Mass Measurement**	**Biosensor**
Subtype	Movement	Orientation	Temperature	Volume	Blood
	Velocity	Inclination	Humidity	Pressure	Organ
	Inertia	Proximity	Luminance	Density	Mental
	Vibration	Presence	Acoustic	Deformation	Tissue
	Acceleration	Location	Radiation	Viscosity	
	Rotation		Gas	Flow	
			Magnetic Field	Load	
			Weather	Moisture	
			Chemical	Shock	
			Electrical	Contact	
			Color	Strain	
			EMF[2]	Corrosion	
				Electrical Conductivity	
				Oxygen	

We undertook a three-step bottom-up strategy to organize this classification: (i) the discovery of sensor instances, i.e., the identification of sensors used in certain scenarios; (ii) the grouping of sensors instances with similar measures, allowing the creation of subtypes; and, (iii) the definition of general terms or "types", for grouping the identified subtypes. The identified sensors types were:

- **Motion** – groups the measures related to the movement of a body[3];
- **Position** – groups the measures related to the positioning of a body;
- **Environment** – groups the measures obtained from an environment;
- **Mass Measurement** – groups the measures obtained from the measurement of a body or a physical interaction force with a body;

[2] Electromagnetic Field (EMF).
[3] We understand by the term "body" any mass (solid, liquid or gaseous), animate or inanimate.

- **Biosensor** – groups the sensors used for obtaining measures from organisms.

We emphasize that the sensors were grouped by types of measurements they provide, regardless of the technology used to obtain this measurement. For example, a device that produces readings on the temperature of an environment by means of an infrared sensor is fitted in the temperature category, even if the sensor working principle is based on the detection of infrared light. However, variations of infrared sensor are used, for example, for motion detection in security systems, thus put in the motion category.

This sensor grouping is a generic-specific relationship, in which the subtypes of a group have common characteristics; the proposed taxonomy for IoT sensors contains whole-part relationships. From the identified areas and application domains, and from the relation of these with the sensors by means of applications and services, we propose a taxonomy for IoT sensors with three levels: domain, area, and sensors. Thus, a domain is composed of areas, and the areas, in turn, are composed of applications and sensors. The taxonomy does not contain applications, so the sensors are directly related to the application areas. The proposed taxonomy is shown in Figure 1.

Domain	Industrial			Smart Cities			Healthcare	
Area	**Agriculture**	**Logistic**	**Plant Floor**	**Transport**	**Buildings**	**Environment**	**Monitoring**	**Management**
Sensor (subtype)	Chemical	Gas	Acoustic	Acceleration	Acceleration	Acoustic	Acceleration	Acceleration
	Conductivity	Humidity	Chemical	Acoustic	Acoustic	Chemical	Blood	Location
	Gas	Inclination	Contact	Contact	Color	Conductivity	Emotion	Luminance
	Humidity	Location	Gas	Gas	Deformation	Corrosion	Gas	Pressure
	Location	Luminance	Humidity	Inclination	Flow	Density	Humidity	Temperature
	Luminance	Pressure	Inclination	Load	Gas	EMF	Inclination	
	Moisture	Shock	Inertial	Luminance	Humidity	Flow	Movement	
	Pressure	Temperature	Location	Magnetic Field	Inclination	Gas	Organ	
	Temperature	Vibration	Luminance	Moisture	Luminance	Humidity	Orientation	
	Weather		Moisture	Movement	Magnetic Field	Load	Presence	
			Movement	Oxygen	Movement	Location	Pressure	
			Orientation	Presence	Orientation	Luminance	Radiation	
			Presence	Pressure	Presence	Moisture	Temperature	
			Temperature	Proximity	Pressure	Movement	Tissue	
			Vibration	Shock	Proximity	Pressure	Vibration	
			Volume	Temperature	Temperature	Proximity		
			Weather	Velocity	Vibration	Strain		
				Volume		Temperature		
						Volume		
						Weather		

Figure 1. Taxonomy of IoT sensors.

The domain level of the taxonomy consists of three domains that encompass all areas and sensors. These domains are Industrial, Smart Cities and Healthcare, and were adapted from Borgia's work in [8]. We assume in this work that they represent the main application domains of the IoT. The terms contained in the area level were defined based on terms commonly found in the literature [2, 8, 9, 15] and used by the authors to describe their applications. Thus, eight areas of application have been identified. The areas of agriculture, logistics and plant floor are related to the industry domain. Transport, buildings and the environment areas are related to the smart cities domain. Finally, monitoring and management areas are related to the healthcare domain.

In the industrial domain, the agriculture area involves all applications focused on agricultural activities such as planting, monitoring, irrigating, and harvesting. The logistics area involves applications related to the distribution chain and product lifecycle management. The plant floor area involves all activities related to security, monitoring, controlling and manufacturing in the industrial sector. The works in which we identified applications for the areas of the industrial domain were [6, 10-12, 13, 17, 24, 41-53].

In the smart cities domain, the transport area involves applications focused on cars, traffic flow, finding better routes and smart parking. The buildings area is focused on applications for the automation of services related to buildings, such as security and home automation, security in public buildings and infrastructure monitoring. Moreover, the environmental area is composed of all services focused on monitoring and acting on the environment, such as monitoring of air pollution and noise, wildlife preservation, and climate monitoring, for the detection of natural disasters and subsequent actions to mitigate their effects. The works in which we identified applications for the areas of the smart cities domain were [7, 19-23, 49, 51, 52, 54-73].

In the healthcare domain, the monitoring area involves services used to monitor vital signs and diagnose patients. The management area involves services to improve management in health institutions, enabling monitoring of patients, staff and equipment, and environmental conditions. The works in which we identified applications for the areas of the healthcare domain were [8, 14, 18, 25, 27-30, 38, 49, 51, 74-79].

The IoT application scenarios were used to define the areas and identify the sensor subtypes present in each area. The terms used in sensor level were obtained from the subtypes found in Table 1. Thus, we built the third level by binding subtypes of sensors with the area in which they can be applied. In addition, it is worth noticing that due to the whole-part nature of the taxonomy, the same sensor subtype can appear several times for different areas. However, this is an expected behavior, since the use of sensors depends on the purpose of the IoT applications. These, in turn, depend on the ability of the IoT designers to generate creative solutions and make use of available resources (sensors, other devices and technologies) in the context of the problem they intend to solve. Moreover, new contexts that emerge daily in consequence to the dynamics of the real world eventually demand the development of new sensor types.

The most used sensors on IoT applications and services are the temperature, humidity and gas sensors, appearing in a large part of the works analyzed and in almost all areas defined in the taxonomy. For the industrial sector, we identified that the most commonly used sensors are the temperature, humidity and gas sensors. For the smart cities domain, the most commonly used sensors are the temperature, humidity and luminance sensors. In addition, for the healthcare domain, the most commonly used sensors are biosensors for organs and blood, and temperature sensors. The widespread use of temperature, humidity, gas and luminance sensors can be attributed to the universal phenomena they observe and the availability and variety of prices in which they can be obtained [2]. As for the biosensors, the emphasis in their use is in the healthcare domain, which is focused on health and quality of life of patients and uses several types of biosensors.

Finally, it is possible to notice that a wide set of solutions combine the use of conventional sensors with RFID and GPS technologies. This is understandable since RFID is present in the IoT since its first steps, and GPS is a well-established technology that provides useful information about the location of things and people.

5. Conclusion

In this work, we have analyzed several solutions to identify areas and domains of application of IoT and the types of sensors employed in these solutions. We have identified various sensors types, according to their collected data type. We have summarized the existing IoT sensors by their type and subtype, and built a taxonomy for IoT sensors by relating areas and application domains with the types of sensors found in current IoT initiatives.

Since this is a work still in progress, we consider as limitations of it the non-exhaustive list of documents analyzed during the first step, mostly of academic nature. As future work, we intend to extend the proposed taxonomy by investigating new IoT applications, and by using data from IoT solutions provided by companies. Furthermore, we could identify more areas and subareas within the application domains, and evaluate and explore some other characteristics of the sensors, apart from those already used in this work.

The taxonomy proposed here can be used as a resource to aid IoT designers, developers and researchers in the process of identification and selection of sensors, as well as in the categorization and recognition of the main sensors used nowadays in the main IoT application areas. Although this taxonomy is a snapshot of the moment, we believe it can be used as a reference for further IoT application development.

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BND: A Proposal of a Business Needs Documentation for Software Solutions to Business Analysts

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Abstract. The main role of a business analyst is to assimilate information from a business domain and present it in a clear and understandable way to the addressees. However, in the case of Software Engineering there is absence of artifacts able to consolidate all information relating to business needs. This study, conducted through a directed search on the subject and a bibliographic research as well, presents a documentation proposal of business needs for software projects. Given the problem, the structure of the proposed artifact can help at later stages of the business analysis by giving valuable inputs for the development of a software solution.

Keywords. Business Analyst. Software Documentation. Business Needs Documentation.

Introduction

One of the tasks that a business analyst tackles in a project scope is to comprehend information of a business domain and present it in a clear and understandable way to the addressees. This statement is valid to any type of project, and this is a primary task for the success of software projects [1].

When it comes to software projects, clients have difficulties in evaluating, by means of Information Technology documents, the progress of what is specifically being proposed and developed. This means that clients need a clear and explanatory high-level system-requirements report, without much technical specifications. However, the team that is developing the system needs this detailed objective and technical specification of what they are developing.

Although Software Engineering provides several techniques, methods and tools for the software industry [2], there is a lack of comprehensive techniques to collect the needed information from the client's business domain. This shortage makes difficult the conception of a solution that can fully meet the business needs. Besides that, in many software projects, especially the remote ones, direct contact with clients is not

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always possible to happen; neither is always possible to count with their full availability to answer frequent questions related to the project [1].

Aiming at diminishing these difficulties, the methodology Rational Unified Process (RUP), as well as the norm IEEE - Recommended Practice for Software Requirements Specifications (IEEE 830-1998) [3] and the Unified Modeling Language (UML) are being currently used in the software market. These examples offer models and diagrams that deal with software requirements in detail, and improve the understanding of the IT team concerning the construction of an information system [4]. However, depending on the characteristics and extent of the project, the creation of the proposed artifacts is not always viable. Furthermore, these artifacts are not always plainly clear to the client, who does not have technical knowledge to do so [1].

In this context, this paper aims at proposing an artifact of business documentation. The research was based on the experiences of the researchers with software project management and on an action research to support the understanding of the constructs discussed. Moreover, methods and techniques relevant to the subject under study as well as gaps in documentation templates already proposed were sought. This paper contributes to the area in the sense that it builds a formal structure to approach aspects that contextualize the business needs (raised during the process of business analysis in the context of the software development) in order to improve the understanding of both clients and software developers.

Regardless how the software development is being managed, the content of a project artifact for the documentation of the business needs should have information to work as input to the activities of Software Engineering and requirements. This content should provide as well a clear and objective language to the client, thus facilitating communication and validation of the business needs.

1. Theoretical Framework

The bibliographic search was done in databases such as Scopus and Web of Science, by using the term “business analyst” in the first search, and the words “software” and “documentation” in the second one. Besides that, as a complement, other literary sources related to the theme were located to give support to this research.

1.1. Business analyst

The role of the business analyst requires a diverse set of skills. This professional is commonly needed in initiatives for changes in processes and is responsible for gathering business requirements and proposing technology information solutions [5] [6].

Business analysts must have knowledge of corporate strategies of the company they work for, and of those of its clients as well. Therefore, the business analyst can guide the process of decision-making maintaining each one of the decisions at hand faithful to the objectives of the parts involved [1].

This professional needs to present the benefits of the business that is being offered, showing the value of the product or service to be provided in the future. It is necessary for the business analyst to maintain high credibility towards the clients, thus guaranteeing the fluency in communication. Likewise, the relation with the technical team must be of high confidence, since the IT area depends on this professional to provide the intended business solutions [6].

Fluency in the languages of the business-related area is another important skill to the work of business analysts because they depend primary on the communication, working as a bridge between the IT area, which uses technical languages, and the clients. Because most of them are not experts in this area area, clients need a more comfortable, clear and objective language to their business. For example, to fulfill this need, the business analyst could use the term "Return on Investment (ROI) instead of "Java" or "Firewall"," [6] [1].

When collecting the requirements, domain areas are analyzed aiming at the improvement of the business operations [7]. To a business analyst, the investigation of the business systems is necessary as well as the gathering of a set of possibilities able to supply the demands in a more efficient way than the current one (s) [1].

In addition, the business analyst has the role of assuring the effective use of the information systems, which should be oriented to the real needs of the business. This way, this professional offers the necessary inputs with precision, so the solution developed by the IT team can fulfill the clients' needs.

1.2. Processes modeling

Processes modeling tools enables to map different levels of detail from the domain area, which means that processes models and activities related can be built hierarchically. When there are different options to make changes in the processes, the modeling facilitates the evaluation of the performance, making it possible to do a quantitative analysis that may contribute to find suitable decisions [8].

The purpose of the modeling is to represent, in a precise and full way, the functioning of a project. The level of detail and specificity of the model are related to what is expected from this initiative, that is, a simple diagram can be enough in certain cases, whereas other situations may demand a complete and well-detailed model [5].

The pattern Business Process Model and Notation (BPMN) is a pattern created by the Business Process Management Initiative (BPMI) and incorporated to the Object Management Group (OMG). This pattern presents a set of solid symbols to the modeling of different aspects of business processes and has been adopted by the main modeling tools of the market [5].

1.3. Software engineering models for the documentation of business needs

In the Software Engineering area there are entries and outs. Entries are basically all the inputs necessary to the activities of Software Engineering, such as: deadlines, restrictions, tools, resources etc. Outs is the software product per se, that is, the solution provided [9].

Inside Software Engineering there is the area of Requirements Engineering, that deals with processes of discovering, analyzing, documenting and validating the system requirements. This area is responsible for a relatively critic stage of the software process, since errors in this phase inevitably bring problems to the project and to the implementation of the system as well [10].

It is important that the Requirements Engineering functions are adapted to the project's needs, and that these functions define what the client really wants, stablishing a solid foundation to the project and to the construction of the solution that will be delivered to the client [2].

Sources such as IEEE 830-1998 norm and RUP methodology have models concerning the documentation of requirements. It is also important to stress that UML is highly used by technicians of the IT area to represent software requirements [4].

2. Method

This research was conducted according to Silva and Menezes [11]. As to the objectives, this is an exploratory and research proposal, since it envisioned a problem through an oriented search; bibliographic search; investigation of methods, normalizations and techniques relevant to the problem; state-of-the-art analysis; proposition and study of real sceneries to evaluate the proposal of documentation to the business needs.

In what concerns the nature of the research, this one is an applied one since it is based in a set of existent theories and theoretical frameworks with the intent to provide a documentation model of business needs.

Regarding the approach of the problem, this is a qualitative research because it aims at constructing a proposal of documentation whose phenomenon interpretation and attribution of meaning do not require the use of statistical methods or techniques.

In relation to the technical procedures, this research is an action-research since it is empiric and strictly associated with an action or with an attempt to look into a collective problem, in which the researchers and representative participants of the problem are involved in a cooperative and participative way. This research is conducted inside an organization with the objective to solve a real-world problem, in which clients and researchers collaborate to the development of a diagnosis and solution of a problem.

3. Results

With the understanding of the responsibilities and competencies of the business analyst role, along with the analysis of techniques and methods used in the process of eliciting business requirements, as well as of the existent models, it was possible to provide a proposal of model to the documentation of business necessities named Business Needs Documentation (BND).

The researched models were analyzed and used as a basis to propose the BND. Because the existing models of Requirements Engineering have a too technical and detailed approach, thus turned to the IT area, it was identified the necessity of proposing a new model.

In many cases, the business analyst, such as the client, does not have a deep knowledge of the IT area and the software engineering processes, which makes difficult the understanding of specifications that are too technical [10]. When the stage of gathering business requirements is not clear enough and the delimitations are not well established between the business analyst and the client, there is a high risk to the solution not fulfilling the real needs of the client's business [4].

In Figure 1 it is possible to see how communication occurs between client, business analyst and the IT area. The BND specifies and documents the needs identified by the business analyst and works as a means of communication between the interested parties.

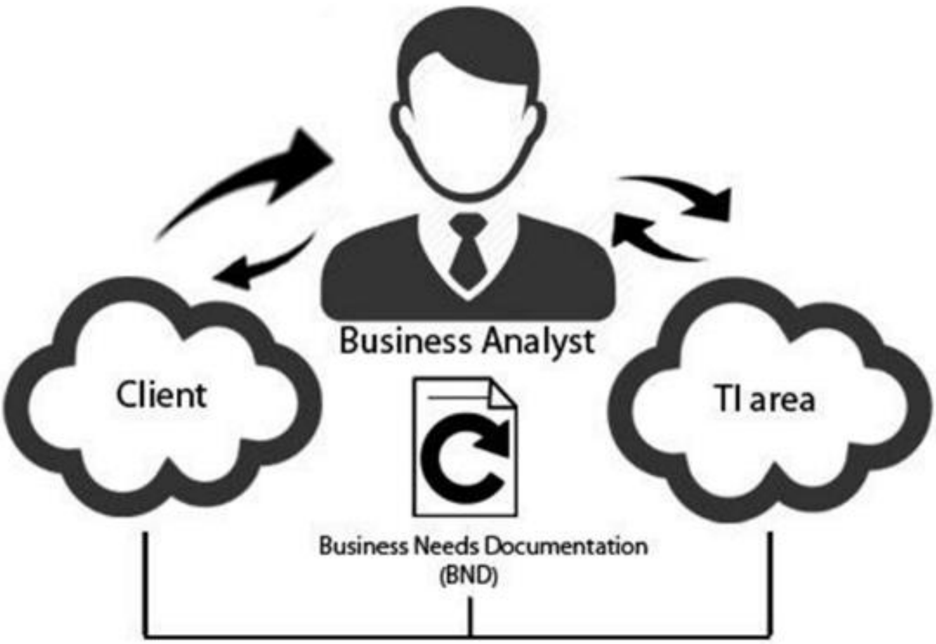

Figure 1. Representation of the communication in a software project using the BND.

The modeling notation of business processes chosen was the BPMN, instead of UML, to represent the processes flow. This was so because UML is a very technical language, whereas the BPMN has its understanding and use spread into several organizations because it offers flowcharts and other diagrams more attached to the understanding of business needs. Besides that, BPMN is versatile to the point that it enables to model different business situations, and can be presented to diverse target public [5].

The BND structure is organized in a set of sections. Each section is responsible to raise a type of information associated to the business need. In the following sections, the objectives of each element that form the structure of the document is described.

3.1. Introduction/Business terminologies

This section aims at describing general information about the functionality that will be proposed according to the business needs. In order to provide a definition of all the terms (of the organization that is demanding the service) required to proceed with a successful interpretation of the following sections, a brief introduction of the functionalities' purpose (context view) is done. In addition, an explanation of the theoretical information associated to the terms is given, which are related with the business domain and not with the technical solution that will be specified afterward.

3.2. Current situation and proposed solution

This section is divided in two phases. In the first phase, the focus relies on describing how the organization (client) do (or does not do) the activities that involve the business needs, also identifying whether these activities use tools or not, including worksheets. In the second phase, the solution given to the process by the business analyst (phases, activities and information that the technical solution must have to meet the business needs) is written. This solution intends to fulfill the needs described in the former phase, and then will be validated by the client.

To improve the understanding of the client, besides the textual support, the pattern BPMN is used in both phases to provide diagrams so that the validation can be expanded.

3.3. Necessary information for carrying out the activities

The purpose of this section is to differentiate which information is needed to carry out the project of the proposed solution. The required information can be found in several types of sources (data, worksheets, documents in pdf. format etc.). It is relevant to highlight that technical specification such as database, type or format in which information is displayed will not be considered at this moment.

3.4. Stakeholders involved in the process

Focusing on the organizational role, this section describes general information that can textually represent the different types of users of both current situation and proposed solution. What is important in this moment is to try to understand in a macro perspective the characteristics and benefits of the stakeholders that play the roles involved in the project.

3.5. Constraints and additional observations

This section approaches different kinds of information that was not described in the aforementioned sections and that can be relevant to the client's validation process and helpful to the technical team.

3.6. Client's documents and files

The purpose of this section is to catalogue the documents of the client that will be used as a support during the elaboration of the current situation and proposed solution.

4. Conclusions

The artifact proposed in this paper can assist in the communication among the parties involved in a software project, since it can work as an input to the phases of software development that follow the business analysis. This means that this artifact can work, mainly, as an input to conduct the processes of software and requirements engineering. Besides that, this document can work for the interaction with the clients, making explicit their needs and describing the business processes and the possible solutions to fulfill these needs. Therefore, the documentation should be composed by clear, concise and complete language concerning the objectives that must be achieved.

The models existent in literature to register the needs of a business within projects concerning software development have a complex structure, with many terminologies, which makes difficult the interaction with the client. Bearing this in mind, the model that is being proposed in this research (described in section 4) is less complex than the other ones, since most of the clients do not have technical knowledge, and the business analyst is not necessarily an expert in the area of Information Technology. Yet the document is less complex concerning Information Technology terminologies, it has to work as an input to the software development team, so that they have all the necessary information to build the system.

The artifact of the proposed project is divided into sections that focus on situating the interested parties, presenting the current situation of the business and a possible solution, synthetizing the necessary information to carry out the processes activities of the client, and documents and files related to the business.

The next step of this research is to apply the BND in a software project in order to prosecute a performance evaluation of this model and identify possible gaps that need adjustments. This will provide content for future publications that will contribute to the scientific community. One of the possible adjustments that can be mentioned is the use of the initial phases of the Design Thinking as a support to the elaboration of the document that is being proposed. Design Thinking would enter in this context to give support to build information to compose the document, as well as to the interaction with the client.

Moreover, we intend to conduct a systematic review of literature to evaluate studies on the subject and verify if the issues raised were answered, and identify which ones should we rely on to continue the investigation and improvement of the model.

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Analysis of Curitiba's Public Transport System as a Complex Network

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Abstract. A public transport system (PTS) can be modeled as a complex network, composed by a large number of vehicles stations (for buses, trains, and so on) as nodes and their connections as edges. The complex network model allows the adoption of metrics and tools based on them aimed to analyzing the public transport system. In this work, the Curitiba's Public Transport Network was analyzed as a complex network, whereas crowded areas of bus lines and locations with deficient number of bus lines could be identified. The usefulness and effectiveness of numeric methods based on complex network analysis are demonstrated through the simulation of adding and removing categories of bus lines to verify their influence in the city transportation system.

Keywords. complex networks, public transport system

Introduction

Transportation network systems can be represented by graphs, with vehicles (cars, planes, bus, train, light rail) stations (or stops) as graph nodes (or vertices), and the path or routes between the stops as links (or graph edges) [1][2][3][4]. Higher networks can be found in large cities, requiring novel computing and mathematical techniques to extract useful information for their planners.

Complex networks (or graphs with some particular statistical characteristics) have been used to model several real-life scenarios like physics, social networks [5], biological structures [6], mobility modelling [7] and transportation networks [3][8]. The analysis performed over complex networks have allowed the identification of particular patterns of nodal connectivity and important nodes (like potential hubs for airplane routes or terminals), for example. By applying metrics on complex network models of real-life entities, the analysis of such entities can be simplified, their networks evaluated and measured to find important information like main and weak nodes, and the type of connectivity, for example, aiming to improving resilience.

In order to analyze public transportation systems (PTS), complex network techniques has been used in order to statistically characterize them. Its metrics has allowed comparison between distinct transportation systems of different cities. Some studies have defined that networks modelled from bus-based PTS (like Poland cities [2] and Chinese cities [4]) are hub-oriented (so-called scale-free networks) while train-based PTS does not have central hubs (so-called small-world networks).

This work analyzed Curitiba's public transportation system (CPTS) as a complex network by considering it as formed by several categories (or groups) of bus lines; each line category presenting a dominant characteristic: for example, bus lines serving only downtown area, bus lines connecting downtown to remote city neighbors, and bus lines connecting only city neighbors. Different from other studies involving network transportation systems and complex networks (which focused on obtain average metrics from the whole network), a method to evaluate how each bus line category in a city (here, Curitiba, Brazil) affects their user mobility is proposed. This method is based on building several L-space [2] complex networks and computing their complex network metrics (average and distribution degree, average and distribution path length). These results showed that is possible to rank the bus line categories and to identify their dominance in Curitiba's bus network.

The work is organized as follows: first Curitiba's public transportation system, complex network theory (including the complex network metrics), and the L-space model for representing transportation system are described. Next, the results from complex networks achieved by changing group of bus lines are presented and discussed, along with a comparison with similar networks from other works. Finally, a conclusion of the analysis is presented.

1. Materials and methods

1.1. Curitiba's Public Transportation System (CPTS)

Curitiba is worldwide known from its bus rapid transit (BRT) system. The public transportation system of Curitiba (hereafter denoted as CPTS) has been exclusively composed of buses (unlike other big Brazilian cities where surface or metropolitan trains are part of a multimodal system). Data provided by the CPTS operator (known as URBS - Urbanização de Curitiba) and Curitiba city managers reflects the citizens commuting service inside the municipality as well as its neighbor's cities.

Considering public data from February 2016 [9], this transportation system was composed with 250 bus lines whose fleet had 1.320 buses, daily serving 1.620.000 passengers [10]. The bus routes traversed 6.737 bus stops. The CPTS has three kind of bus stops (or stations): regular bus stop (supporting a reduced number of passengers and identified by simple info boards), "tube" stations (a glass-metal structure to support a moderated number of passengers), and terminal stations (a large infrastructure to support high number of passengers).

Generally, the terminal stations are connection terminals (equivalent to hubs) that serve several bus lines in Curitiba bringing passengers from regular bus stops and tube stations. Once in a terminal station, passengers could get into buses from another bus route without paying additional fare. It is important to note that Curitiba does not have a downtown (or central) terminal.

The bus routes in CPTS have been divided in different categories according to the original design of CPTS [11]: there are bus lines traversing the city on north-to-south and east-to-west exclusive roads, and bus lines connecting directly downtown to remote Curitiba´s neighbors, for example.

Briefly, the CPTS has been formed by the following eleven categories of bus lines, all of them associated to buses of distinct sizes and colors as a pictographic id:

- Express ("Expresso"): the bus lines are associated to red buses. These bus lines connect regular bus stops, bus stations, and terminal stations (at least two terminal stations are part of the bus stops traversed by the express buses). Some of the bus stops are located at downtown area. The buses have high passengers capacity and high frequency, to allow fast commuting between downtown and neighborhood;
- Feeders ("Alimentadores"): the lines are associated to orange buses. These bus lines connect a particular neighborhood with regular bus stops to only one terminal station (a high capacity terminal, a passenger distributor to the main routes). The feeders are operated with buses with medium passenger's capacity.
- Conventional ("Convencional"): the bus lines are associated to yellow buses. These bus lines connect with regular bus stops from/to downtown. The conventional bus lines do not traverse terminal stations;
- Direct Lines ("Linha direta" or "ligeirinhos"): composed by bus lines identified by their gray color buses. Although these bus lines connect tube stations and terminal stations, the geographic distances among their bus stops are greater than the ones found in other bus line categories (3 km, on average);
- "Troncal": composed by bus lines identified by their yellow buses. The "troncal" is a version of "Convencional" bus lines connecting a terminal station to bus stops in downtown area;
- Inter-neighborhood ("Interbairros"): composed by bus lines associated to green buses. These bus lines connect regular bus stops and terminal stations. Their main characteristics are the circular path of bus stop without a starting or ending bus stops out of the downtown area and without traversing it;
- Downtown Circular ("Circular Centro"): composed by bus lines associated to white buses. These bus lines connect only bus stops and encircled the downtown area with small buses of very low capacity;
- Special Education ("Ensino Especial"): composed by bus lines identified by buses of blue and yellow colors. These bus lines serve only special needs students driving then to/from public schools. They have had not bus stops to traverse.
- "Ligeirão": composed by bus lines running big blue buses. The bus lines are superseded versions of Express lines (also connecting regular bus stops and at least two terminal stations). The geographic distance among their bus stops are greater than the ones found in "Expresso" lines.
- Tourism ("Turismo"): composed by double-deck buses, they have bus stops located near import sightseeing places.
- Late-night bus lines ("Madrugueiros"): bus lines operating from zero to 6 AM. They are characterized by having a high number of bus stops to traverse (not including terminal stations, that have been closed during this time).

Data about each of these categories are shown in Table 1, with their number of routes, buses and stops. Figure 1 shows a pictographic description of such network.

1.2. Complex Networks

Graphs have been used to model networks, including transportation networks [1], in which a set of elements (nodes) are connected to each other (by edges) according to a set of rules. Complex network theory deals with graphs and networks, consequently, that do not present random or orderly connections.

To statistically characterize different complex networks, several metrics have been developed [2] as: the number of nodes (N), the average of all nodal degrees (a nodal degree is the number of links connected to it, or number of a nodes neighbors), the curve of degree distribution (relative to the frequency of nodal degrees), the average path length or average distance (the distance between two nodes is shortest path, or the least number of nodes traversed to connect them), the diameter (the highest path length in the network), and the average clustering coefficient (the clustering coefficient of a node measures the ratio of connections between its neighbors). All these metrics evaluate topological characteristics of the nodes and their connections. For example, low diameter represents high interconnectivity in a given complex network.

Using these metrics, it is possible to classify complex networks as:

- Random graphs [13], whose degree distribution is a Poisson distribution, has both low diameter and low clustering coefficient.
- Small-world [14], whose most of the nodes can be reached from the others through few numbers of intermediate nodes, and has high clustering coefficient (such a network can be observed on social networks).
- Scale-free [15], whose degree distribution is a Power-law distribution (a few nodes have high degree and vice-versa). These few nodes with high degree act as hubs or influencers (such characteristic is currently named as preferential attachment). One good example for scale-free network is one formed with airlines routes.

1.3. CPTS as a complex network

CPTS was modeled as a complex network using a L-Space [2] representation. It means the bus stops were represented as nodes, and edges were created for all pairs of successive bus stops of all bus lines. Therefore, 16.000 edges were created connecting two bus stops (nodes) used by 250 bus lines. In case of Curitiba, there were no difference between nodes representing regular bus stops, terminals, or tube stations in its complex network representation. All the edge weights were set to one. The generated complex networks were undirected graphs, since this type of graph has been commonly adopted by other studies [2] [4].

Additionally, some of the bus line categories were excluded from the analysis since they were related to attend special users (tourists, students, and off-work hours). They were: "Downtown Circular", "Late-night bus lines", "Special Education", and "Tourism". Therefore only the following bus line categories were considered: Express", "Feeders", "Conventional", "Direct lines", "Troncal", and "Inter-neighborhood".

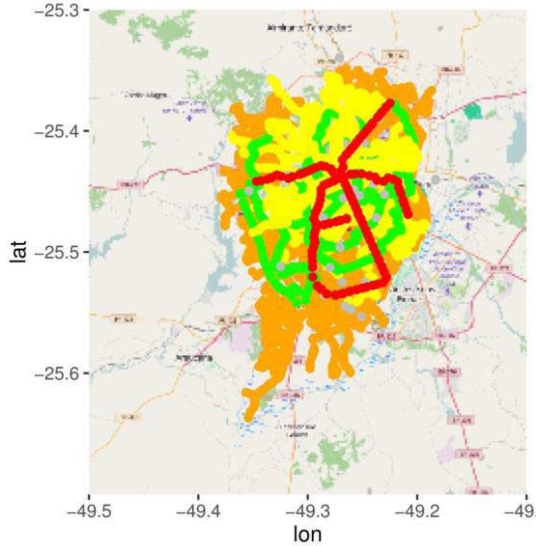

Figure 1. Curitiba CPTS pictographic bus categories view. Map of the city were acquired from OpenStreetMap [12].

Beside the complex network formed with all the bus lines belonged to these categories, individual complex networks were built for each category. Finally, complex networks formed by excluding each category (as a complementary complex network of each bus line category). This was made to evaluate the influence of different categories of bus lines in CPTS.

The following metrics were calculated from all the above complex networks (their mathematical description are in [2], [3], [8]):

- Average degree (or <k>): the average value of the number of existing connections between bus stops.
- Degree distribution: a histogram of the probability - p(k) - of connections between bus stops. It gave the probability of having a node with degree equals to k.
- Average path length (or <l>): the average value of the path lengths (shortest ones) between all pair of bus stops. It measured the average number of bus stops that a user should traverse between any two bus stops.
- Diameter: the maximum path length (between two nodes) in the network. It measured the number of bus stops that a user should traverse between the two farthest bus stops in CPTS (in terms topological connectivity).
- Path length distribution: a histogram of the probability - p(l) - in the network. It gave the probability of having a path length equal to l. Number of connected components (or NC): the number of subgraphs in a complex network. A totally connected complex network has NC equals to 1. Values greater than that indicates transportation networks formed by disconnected group of bus lines.
- Clustering coefficient (or <C>): it measured the tendency of a complex network have cluster of connected nodes. This indicates if a transportation network is hub-based or having small-world behavior.

2. Results and Discussion

Table 1 summarizes the statistical characteristic of individual bus line categories, their influence over the total transportation network, and the statistical characteristic of CTPS. From one bus stop, an user in the full analyzed CTPS had to traverse 38 other bus stops (on average) in order to reach any other bus stop, since <l>=37.154. The farthest bus stops in CPTS were separated from each other by 107 (network diameter minus 1) bus stops. Additionally, each bus stop was connected to 5 (also on average) other bus stops, since <k>= 4.853.

Individually, the bus lines in the categories "Conventional", "Direct lines", and "Express" were totally connected since NC = 1. It happened because some of their bus stops were terminals where several bus lines converged to. Lines from category "Feeder" were grouped into (NC =) 8 different and unconnected complex networks although being formed by 174 bus lines.

Table 1. Complex network metrics of different bus line categories, their combinations and full CPTS. <k>means average degree, <l>means average path length, NC means number of clusters, and <C >means clustering coefficient.

Category	Routes	Stops	Links	<k>	<l>	Diam.	NC	<C >
Direct Lines	31	121	515	8.512397	5.553857	12	1	0.09615385
Express	12	224	798	7.125000	18.618714	46	1	0.01709402
"Troncal"	17	631	1005	3.185420	21.002954	56	5	0.01910828
Inter-neighborhood	9	779	2230	5.725289	37.791395	102	3	0.06493506
Conventional	83	2560	4866	3.801563	31.525730	84	1	0.03714404
Feeders	174	3849	6845	3.556768	67.455225	232	8	0.02598178
Full CPTS minus Direct lines	295	6616	15744	4.759371	37.165121	108	4	0.04303764
Full CPTS minus Express	314	6513	15461	4.747735	37.176935	108	4	0.04525567
Full CPTS minus "Troncal"	309	6516	15254	4.682014	38.142781	108	6	0.04517145
Full CPTS minus Inter- neighborhood	317	6518	14029	4.304695	42.902048	118	6	0.03656925
Full CPTS minus Conventional	243	5088	11393	4.478381	48.231705	131	5	0.0384998
Full CPTS minus Feeders	152	3675	9414	5.123265	27.171522	85	4	0.05272408
Full CPTS	326	6737	16259	4.826777	37.153535	108	5	0.04462462

Figure 2 presents the degree (<k>) distribution of CPTS (including a cumulative degree distribution in log-log plotting). It clearly resembles the distribution of scale-free (or hub-based) networks: A few nodes (like terminals or high traffic bus stops) served most of the bus lines (high degree), and vice-versa.

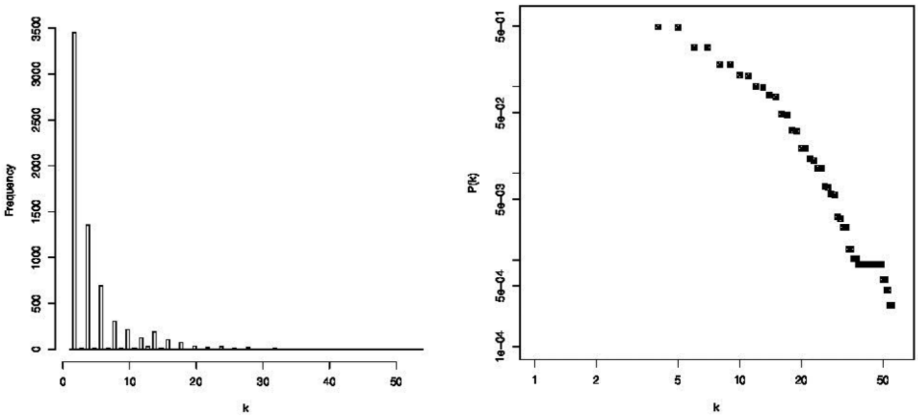

Figure 2. Degree distribution k (a) and cumulative degree distribution P(k) in log-log plotting (b) of a complex network representation of CPTS.

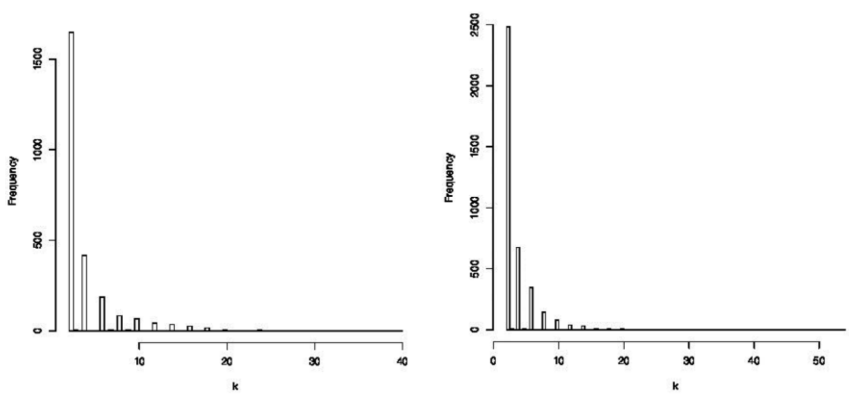

Figure 3. Degree distribution of bus line categories (a) "Conventional" and (b) "Feeders".

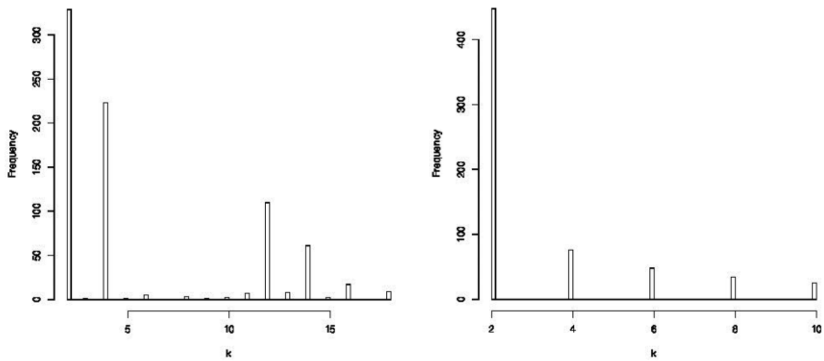

Figure 4. Degree distribution of bus line categories (a) "Inter-neighborhood" and (b) "Troncal".

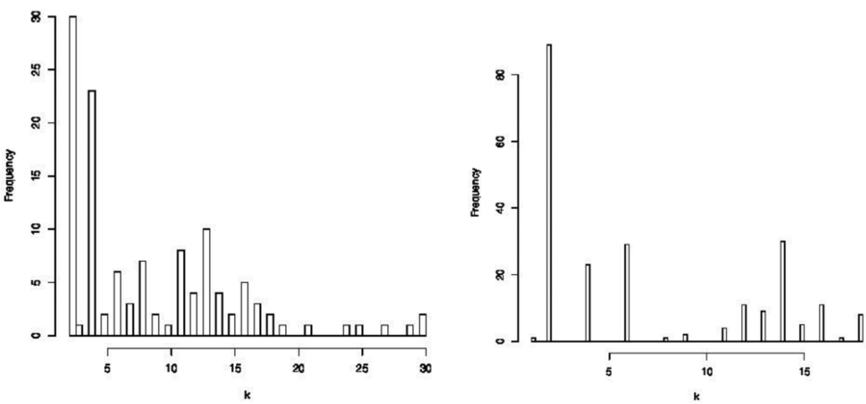

Figure 5. Degree distribution of bus line categories (a) "Direct lines" and (b) "Express".

Category "Inter-neighborhood" presented the highest ratio between number of unconnected networks and the number of bus lines and the (3/9), followed by Category "Troncal". Therefore users would require change bus to access some of their bus stops.

Topologically, bus line category "Direct lines" had the lowest network diameter and average path length. Readers should consider that the distance between their bus stops are the highest in CPTS. By presenting the highest clustering coefficient and the lowest path length, this category formed a complex network with small-world characteristics.

By removing bus lines of categories "Conventional" and "Feeders", an increase and a decrease of network diameter was respectively observed. In case of "Feeders" ones, since their bus departed from and arrived to terminals (acting as network hubs), they expanded the network diameter and path length.

Bus lines of category "Conventional" formed a completed scale-free network since its network distribution degree had a Power-law distribution. As mentioned before, these lines connected downtown area to other neighborhoods. They seemed to add alternative routes to bus users, since their removal from CPTS increased both the network diameter and the path length. They also reinforce the scale-free characteristic of CPTS.

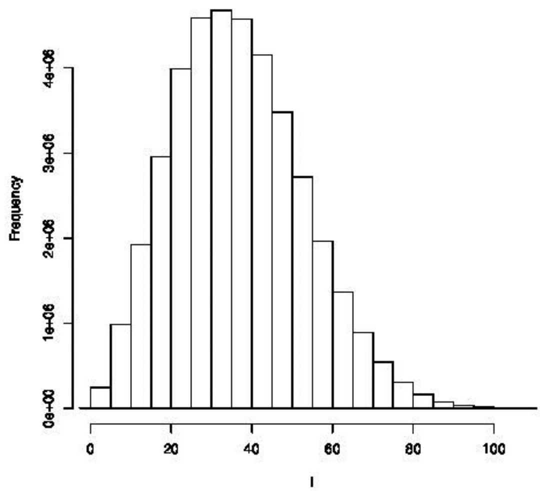

Figure 6. Distribution of complex network shortest path of CPTS.

Comparing the results with [2], Poland cities had higher cluster coefficient (0.085 for its bigger city, whose N = 2811), and lower <k>and <l> (respectively 2.83 and 19.76, for the same city). The same profile has been observed by comparing CPTS with Beijing bus transportation system [4] (N = 5421, <k>= 3.13, <l>= 20.03, C = 0.142).

Figures 3, 4, and 5 show the degree distribution of each category of bus lines in the CPTS. All categories except "Direct lines", Express, and Inter-neighborhood fit to a Power-law distribution since their distributions were similar to the one from the CPTS (Figure 1). Since lines connected more than one terminal bus stop (i.e. complex network hubs), they seemed to add preferential attachments (or shortcuts) in the network. However, such a characteristic was not dominant in the whole CPTS. Topologically they resembled circles because once users have embarked into one of their bus, they could travel "indefinitely" with only one fare. Additionally the nodes (bus stops) of their individual complex networks did not have degree equals to one, something have not found yet in other studies using complex networks to evaluate PTSs.

Finally, Figure 6 shows the distribution of path lengths between all (two-by-two) bus stops of CPTS. It resembled the distribution of hub-based networks (scale-free complex networks) [15]. From Table 1, the average path length was 37.154 and most of the routes between any two given bus stops in CTPS had path lengths around this mean value. This high number of bus stops to traverse the city by bus was related to the need of users to change bus in terminal bus stops, and the average number of bus stops by bus lines (6737/326 = 20). Shortening such a ratio by adding more hubs would lead to shorter <l>and small-world dominance.

3. Conclusion

The bus-based public transportation system of Curitiba was modelled as L-Space complex network. It revealed some of its category of bus lines behaved as a small-world complex network, specifically the bus lines that topologically resembled circles and connected two or more hubs (or terminal stops). However, CPTS, as a whole, was characterized as a hub-based network (or scale free network).

Complex network metrics revealed that CPTS had a diameter equals to 108, with an average path length equals to 37.154, meaning the citizens had to cross 38 bus stops to reach their destinations (on average). These metrics could be translated to physical distances by assuming the average distance between two bus stops. It was shown that some categories ("Conventional" and "Feeders") of bus lines significantly affected the complex network metrics (as diameter and average path length).

The presented results show that city planners, for instance, could use complex networks to assess the public transportation systems of their cities in order to improve the service effectiveness by increasing the number of bus lines in categories that reduce the network average path length, for example.

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Part 6

Multi-Disciplinary Product Management

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Managing Dependencies in Heterogeneous Design Automation Systems

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Abstract. Increasing competition in cost efficiency, lead-times, product quality, quotation accuracy, and abilities to provide customization drives companies toward development and adoption of new methods. To re-use knowledge gained from previous projects in order to avoid producing the same knowledge again and to circumvent previously encountered obstacles is an approach which is more or less used by most companies. Utilization of Design Automation (DA) systems in the engineering design process have proven to increase process efficiency and to enable new ways of working by systematic re-use of engineering knowledge. In order to ensure system longevity, industrial practitioners and researchers have pointed at implementation and long term management as important aspects to consider during development. The systems are often built on top of commercial software and legacy systems integrated by different types of scripts and system descriptions which becomes dependent of each other in different ways. Changes made during maintenance in one of these artifacts propagates through the dependency structure making traceability and transparency key factors for keeping the system valid over time. This paper presents a description of the problem in a real industrial setting together with a suggestion of an approach, based on set-up and management of dependencies between sections inside and across different types of system components, which is aimed to aid implementation and management of DA tools. A prototype system which informs the user, of functional sections related to a functional section to be updated, have been developed. The prototype is applied on a multidisciplinary heterogeneous system environment used for simulation based knowledge build up and concept evaluations of jet engine components.

Keywords. Design Automation, Dependency Management, Customization

Introduction

OEMs and consumers are more frequently demanding high levels of customization of products. Subcontractors are significantly affected by this since they need to compete with other subcontractors with providing the most appealing quotation. To be able to meet the demands, the subcontractors' infrastructure have to be flexible enough to be able to provide a large range of external variety and at the same time keep costs low. This increased demand of customization can be reflected in an increasing amount of research within the field of customization [1, 2]. Allowing high levels of customization in manufacturing and development processes generally results in high internal variety, which in turn is related to increased complexity [3] and increased cost [4] of the processes. One way to counteract the increased cost, resulting from increased

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customization, is to actively make use of previously produced knowledge. By re-using knowledge, creation of the same knowledge over and over is avoided and thereby avoiding costs related to the synthesis of the knowledge. Re-use of knowledge also have potential in reducing time since in many cases, less time is needed to implement already existing knowledge than to reproduce it. In technology and product development processes, many attempts have been made to re-use knowledge by letting computer based support tools make use of it in different ways. Design Automation (DA) is an approach which acts on well formalized engineering processes by automatically performing tasks with the help of stored knowledge. There are many approaches to DA which can be used differently depending on i.e. the maturity of the considered process, where in the development process the DA system is supposed to act, or the level of customization the system should enable. What could be seen as the simplest type of customization enabling DA system is a configuration system. Configuration systems make use of a modular product structure which is configured in the most suitable way for a specific customer [5, 6]. Other types of systems, with the ability to provide higher degrees of customization, deals with i.e. parametric design [7], or Knowledge Based Engineering (KBE) [8]. Systems also exists with the purpose of generating and evaluating versions of design concepts, often with the help of simulation software [9, 10]. The Design Automation tools introduces new ways of working when implemented but also comes with an investment. This investment is re-gained if the system can be active long enough to enable savings, or produce value in other ways, proportional to the investment. Over time, processes can change, new requirements can be added to system functionality, new knowledge is added, knowledge is changed, and environmental changes can be made to the environment in which the system is built and operates. These types of changes provides challenges in keeping the system operational over time and companies adopting Design Automation systems have described this as problematic. Amongst others, two areas have been described as underlying reasons as of why these types of changes are challenging and hard to handle. Transparency of the system itself, and traceability of the knowledge which the system makes use of or is built upon [11]. The same paper presents a walkthrough of existing methodologies for system development focused on DA related applications. Concluded from this investigation, it can be seen that existing methodologies does not support implementation and maintenance of the systems being developed. The methodologies however states that these are aspects with importance and affects the success of the final implemented system. Transparency have been pointed out as a factor which affects longevity of DA systems [12, 13] and refers to the ability of accessing the system and its components as well as knowledge used by the system. Low transparency of the system results in time consuming processes for performing maintenance and updates. If parts cannot be accessed, they could over time be rendered invalid, thus reducing functionality, performance and/or accuracy of the system. Traceability will in this context be referred to the ability to follow an artifact, and the knowledge fragments of which it is built from, through its development and life.

In this paper an attempt to provide an approach, which aids implementation and management by proactively introducing traceability during DA system development, is presented. The traceability is gained by keeping track of dependencies between functional sections in the system and through this, providing several possibilities to facilitate management of the system.

1. Dependency management

Throughout engineering processes, large numbers of documents are created. The documents have varying scope and purpose. These documents describe the product from different viewpoints in different levels of abstraction. They can describe legal limitations of products and processes, specify customer requirements, contain knowledge of how to design and evaluate concepts. Dependencies often exists between the documents which can refer each other in many ways depending on the format. Dependencies can act on specific parts of documents, creating a complex dependency structure. Extensive work is required to track these sub-document level dependencies when changes have been made and the document collection have to be checked for consistency.

Documents are often subjected to change during the engineering processes and it is important that they are consistent with each other [14]. The management of documents in such heterogeneous environments have frequently been pointed out as important in order to maintain consistency in document clusters and thereby keeping systems and documents valid [15]. Monticolo et al. [16] addresses this problematic, focused on the engineering design process and expert models connected to CAD and CAE models. They describe the problem in a concurrent engineering perspective where information such as parameters, expert rules, and mathematical relations are shared by several users in different disciplines. They further state that tools existing today is not capable of managing encapsulated knowledge and cannot ensure that information is consistent through different heterogeneous expert models. A Knowledge Configuration Model (KCModel) is proposed with the aim to allow for acquisition, traceability, re-use, and consistency of explicit knowledge used in configuration. The solution for consistency is based on checking every knowledge instance used in a knowledge configuration with all other configurations. Their approach is constrained to explicit knowledge. Scheffczyk et al. [17] proposes the use of strict explicit formal consistency rules in order to obtain consistency in heterogeneous repositories. They present a tool which can be used to automatically achieve consistency or to pinpoint inconsistencies in document structures. By setting priorities to the rules, an impact assessment can be extracted from the inconsistency analysis. Hutter et al. [18] presents a system called MAYA. The system is described as a tool which maintains formal developments. To interact with MAYA, the user translates specifications to a formal specification language. The specifications contain theories in which, when the specification is translated to the formal language, proof obligations are defined to indicate relations to other theories. External theory provers, such as the one presented in [19], can be connected to the software in order to operate the proof obligations.

Most research found which deals with consistency of document clusters are presenting methods of how to automatically achieve consistency by enforcing a set of rules on the content of the documents. Egyed [20] presents a method for automatically detecting and tracking inconsistencies in software design models. Engineers have to define consistency rules which is used by the system in order to automatically detect violations of the rules. The violations are presented to the user which has to evaluate if the inconsistencies are relevant to deal with or not. Xiong et al. [21] introduces a language, called Beanbag, for the purpose of creating automated fixing procedures in software development environments. The language is based on languages for writing consistency relations but is also adapted for the adding of semantics which is used in order to provide a description for the fixing procedure. Spanoudakis et al. [22] have developed a model and a prototype system on the model, used to generate traceability relations. Thus, traceability rules have to be defined manually. These rules are represented in XML from which the prototype system is able to produce four types of traceability relations. A very similar model can be seen in [23].

A lot of research have been done to the considered topic. Methods and tools exists, which helps software developers or other practitioners to keep their document and system environments consistent and updated. Tools exists which can automatically keep track of relations between documents or make changes to code in order to re-obtain consistency. However, in order to build the environments required for the tools to work, a lot of manual work will have to be done prior to obtaining automatic consistency checks. Most of the tools are developed with focus on large scale software development, specific problems or system entities, and are supposed to be used by pure software developers. In the engineering design field, a lot of smaller software tool development projects are performed, without the intention to be part of a larger system in the future, relatable to the System-of-Systems concept. The individual software tools are often developed by the design engineers themselves who are not very prone to doing extensive documentation work, not by software developers.

No solutions have been found which have the ability to explore the content inside different types of documents, keeping track of relations between sections in one document type to sections in another document type, and doing this with a low amount of set-up effort.

2. Dependency management in DA systems

In this section an approach, Figure 1, of how to work with dependency management in DA system environments is presented.

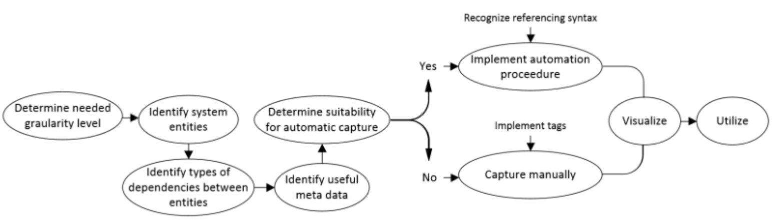

Figure 1. Proposed approach for dependency management in DA environments.

Granularity Levels - Dependencies can be captured in different levels of granularity depending on needs in specific cases. A fine granularity level enables visualization of the system structure in different views. Depending on the purpose for using the system or which person it might be desirable to have this possibility. Setting up the system dependency structure in fine granularity enables different stakeholders to filter the view to suit their discipline or wanted level of abstraction. An example of granularity levels can be seen in Figure 2 where the children of a parent is a finer grained representation of the parent.

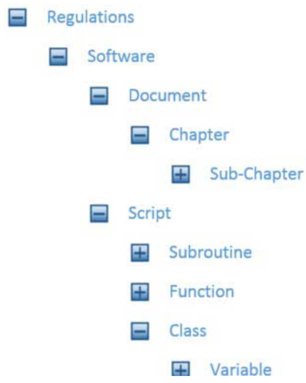

Figure 2. Example of granularity levels

Meta Data - By adding meta data to captured dependencies, or while capturing dependencies, the efficiency of the utilization of the stored dependency structure can potentially be increased. Information about the person who captured a specific dependency enables the possibility to contact this person for consultation when a change is planned for a considered dependency. Descriptions of the purpose of the dependency and how the affected system entities interact technically, enabled engineers to be quickly informed and saves them from going through code or documentation in order to figure this out. If there are any specific demands which are required in order to keep the dependency valid, this could be added here. These could be that a script needs to work against a specific version of a commercial software in order to work, or that a variable need to be kept within a certain range.

Capturing Dependencies - Depending on what type of dependencies exists in the system, they can be captured in different ways. Types of dependencies can be divided in many ways. In this paper dependencies will be divided in two groups, structural, and passive dependencies, as described in [24]. Dependencies can be captured manually or automatically depending on how they are formalized in the system or documentation. If the dependencies occur in a standardized format, these could be found by an algorithm and automatically captured. Dependencies which are not described in a predictable way or if it for some reason is not worth to build the structure needed for automatic capture, they can be captured manually. In this case it is proposed to introduce tags, containing the desired information, to the entities. These tags can be built in such way that an algorithm can find them and thereby enabling a semi-automated capture. Programming languages usually describes several types of dependencies which easily can be captured automatically. These could be relations between subroutines, functions, classes, and libraries. Dependencies which are typically hard to capture automatically are the passive dependencies. These are often described in natural, non-formal language and might have to be captured manually. Cross-platform dependencies can also be hard to capture automatically since communication between two platforms can occur in several different ways. One must ensure that all ways of communication is covered in the algorithm to ensure that all dependencies are captured and that they are captured in the correct way.

Visualization - The captured dependencies can be used to visualize the system structure in different ways in order to obtain overviews of the system. Informative views can be obtained by configuring the dependencies using the meta data and the granularity levels. Utilization of filtering and clustering techniques provides possibilities to create discipline specific views by removing irrelevant parts or by putting focus on relevant parts. By using the granularity levels, views which require more or less previous knowledge about the system can be obtained. This enables creation of visualizations adapted for stakeholders with focus on varying degrees of technicality or abstraction.

Transparency/Accessibility - The dependency structure can be used in order to obtain transparency of the system environment. By providing direct access to system components such as scripts or descriptive documents through the utilized visualization approach, the engineers would not have to search for the files, and could also be guided to the correct place inside the considered system entity without manual navigation or interaction with PLM or version control systems. Interfacing functionality could also provide previews and editing capability of system entities without having to open them in their native development environment.

Impact assessment and change propagation - During maintenance of system entities, it can be hard to assess the effect of a change, to other system entities. The scope of the affected area can vary a lot with different types of changes. Through the dependency structure the engineers can get estimations of the impact of a change depending on what types of relations it have to other system entities, or how many dependencies the entity considered for change have to other parts of the system. The finer granularity of which the system is described in, the higher the accuracy, of the impact assessment, will be.

When a change is made, it will propagate through the system via the dependency structure. Depending on the nature of the change, it might affect components of the system, outside of the changed component. Further change might have to be done to affected components in order to regain consistency. This behavior can thereby keep propagating through the system. By investigating meta data captured in the dependency structure, engineers could determine if change have to be performed to interfacing components.

3. Case Study

In this chapter, a description of the problem in a real industrial setting is presented together with a suggestion of an approach, based on modelling and management of dependencies between functional sections inside and across different types of system components, which is aimed to aid implementation and management of DA tools.

A case study have been performed in collaboration with a company in the aerospace industry. Workshops and interviews were held with several people from the company, working mainly with technology or product development but who also were heavily involved with development of DA systems. Focus of the activities was to further develop the understanding of needs presented in [11].

The company is a global actor in the area of development, production, service and maintenance of components for aircraft engines, rockets and gas turbines with high technology content. The company provides products that are completely custom engineered in an international market with high competition. The products are integrated in complex systems working in extreme environments for long time periods with both customer and legal demands for complete documentation and traceability. The company takes full responsibility for the functionality of their products during its operation including service, maintenance and updates. Fulfilling these harsh requirements is a challenge but at the same time an opportunity to sustain a competitive edge. Automation of design and production preparation by the use of knowledge based engineering (KBE) has been used at the company for more than a decade to enable quick adaptation to changes in customer specifications and evaluation of different design solutions. In order to aid the concept development phase, a multidisciplinary analysis system containing KBE applications is currently being developed by the company. The purpose of the system is to provide knowledge of how changes of the design parameters affects a concept. This knowledge is obtained by performing analyses in a number of different disciplines. Simulations of cycle lifetime, stiffness, buckling, producibility, thermal effects, and more are performed and the results are compiled and sent to the concept developers. The system consists of several different commercial software, controlled and stitched together with in-house developed software and scripts written in several different programming languages. When realizing the systems, the company engineers follow method descriptions called Design Practices together with other documents and knowledge sources. The design practices are directed towards describing the execution of a certain task on a certain component e.g. meshing a CAD model. Connecting these documents to program code are seen as challenging but important in order to obtain high traceability through the system. Over time the design practices as well as the program code are updated and subjected to changes which creates problems in keeping the connection valid. The integration of this kind of systems in its intended environment are seen as an important aspect although problematic. Aspects such as knowledge traceability through the system as well as system output representation are thought to have an impact on the success of the implementation. From the workshops and interviews a set of success criteria, thought to have potential to overcome the main obstacles for DA system success, were derived. For each success criteria a set of enablers, thought to have the ability to enable the fulfillment of the success criteria, were derived. Emphasis of the result from the interviews and workshops could be found around the aspects connected to system transparency and knowledge traceability which was thought to be enabled by connecting related parts of the system to each other.

Figure 3. Welding assembly sequence of a structural jet engine component.

A system that is currently developed at the company was used as subject for introducing dependency management as a means to achieve increased system transparency and facilitated knowledge traceability. The system is used as a module in a larger system which performs a set of analyses in order to build knowledge about concepts. This specific module is used to perform producibility evaluations by analyzing a components geometrical features in relation to available manufacturing processes. The Producibility Assessment System (PAS) is built on two commercial software (Siemens NX, and MS Excel), three different programming languages (VB, VBA, and NX Knowledge Fusion), and has connections to normative descriptions written in non-formal natural language in MS Word documents. The system has been used to perform producibility assessments of a structural component, connecting a jet engine to the air craft wing, Figure 3. 128 versions of the component are automatically generated from a base-line model and run through the system which evaluates the different versions with consideration of, for the company available, welding techniques.

3.1. Applying dependency management

In the test-case with the PAS, most dependencies were captured manually. Automatic capture was performed on one type of dependency. An algorithm was written in python for automatic capture of dependencies between knowledge fusion scripts. The knowledge fusion language is developed by Siemens and is used to perform actions in the CAD software Siemens NX. When the dependency structure was set up on the PAS, the finest granularities consisted of chapters in natural language documents, and subroutines/functions/classes in scripts. This resulted in 81 structural dependencies and 2 passive dependencies. 5 dependencies were caught automatically and 78 were caught manually. 63 of the 78 are directly connected to how the used programming languages calls or executes other entities of the system. Capture of these dependencies have potential in being automated in the same way as the capture of dependencies between the Knowledge Fusion scripts. This means that 82% of the dependencies in this system has potential in being captured automatically with simple algorithms. This is without including possible automatic capture of cross-platform dependencies or attempts to standardize natural language descriptions. In the test case, two different ways of visualization were tested. A natural way of presenting the dependency structure is in a regular tree structure. However, when the system grows and more dependencies are introduced, it can be hard to keep a clear overview at fine granularity levels. Filtering techniques can be used in order to improve the ease of use. For the second visualization approach an open source software for network exploration, Gephi [25], was used in order to build graphs. The graphs show system entities as nodes and dependencies as lines between nodes. Several different layout algorithms can be applied to the graphs in order to produce clear views of the structure. Filtering and clustering techniques can also be applied in Gephi to further improve the usability of the visualized dependencies. A python script was used in order to generate input files, representing the dependency structure of the PAS system, for Gephi. The generated input files were imported into Gephi and resulted in the plots shown in Figure 4, where the color scale from green to red indicates how many interactions a system entity has with other entities. Dependencies can also be weighted in order for certain dependencies to affect the visualization in a way which reflects its importance.

Meta data can be displayed in the graphs and they can be filtered and searched in order to provide suitable views for certain situations.

Transparency was in this case study introduced by providing access to the system entities registred in the dependency structure. Two different technical solutions for achieving this were tested. The user of the system was given the possibility to open the system entity, in its native environment, directly from the visualization tool. Text based entities, such as code or natural language documents, can be displayed in the visualization tool in order to enable quick previews. If a dependency acts on a specific part inside such documents, this specific part is located and displayed for the user in the visualization tool.

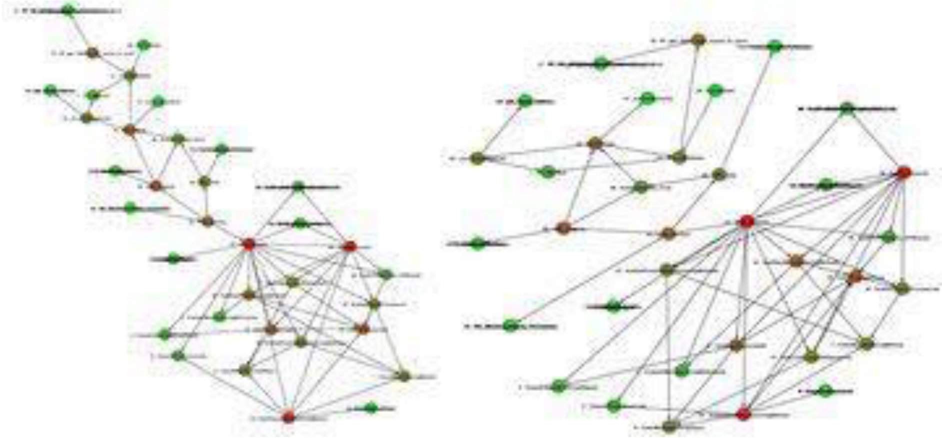

Figure 4. Gephi visualizations of the PAS system.

4. Conclusions

The objective of this work was to introduce an approach with potential of achieving traceability and transparency in heterogeneous system and document environments such as the environment of a typical DA system. The traceability and transparency were introduced with the intention to enable a more efficient maintanance process of the considered environements. An atempt to achieve this was made by introducing dependency management on a sub-document level, allowing cross-document type dependency capturing. Manual labour was cut by introducing automatic capture of certain dependency types. In the test case 82% of the total amount of dependencies had potential for automatic capture. Two important parts of the approach is the consideration of granularity levels and the capturing of meta data. These can be used to create clear and explanatory overviews of the system in which the flow of information and knowledge can easily be traced through the system structure without having to obtain this through document and code scrutinization. A conclusion based on reviewed literature, industrial input, and the case study presented in this article, is that there is a need for approaches which provides traceability and transparency to the concidered type of environments, and that dependency management and visualization seem to have potential in achieving this. However, further evaluation will have to be performed in an industrial setting in order to obtain further verification and validation. Future work will include a more extensive evaluation of the presented approach in the industrial environment of the case company. Visualization techniques and meta data representation will be further investigated.

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E/E-Product Data Management in Consideration of Model-Based Systems Engineering

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Abstract. This paper presents objectives for permeable electric/electronics product data management for mechatronic products in consideration of model-based systems engineering from the early product development phase till a lifecycle management. Idiosyncrasies of mechatronic products, requirements engineering, model-based systems engineering, artifact-orientation, and interconnections of artifacts are evaluated and postulate objectives, how artifacts have to be designed in order to support the linkage of model-based systems engineering and product data management (PDM). The objectives, derived from the different theories and requirements to foster permeable PDM, are: i) Identify all existing norms for the development of mechanical, electronic, and software aspects and elaborate how information artifacts have to be defined. ii) (Textual) Requirements have to be technically feasible to be linked to information artifacts and system models already in the early development phase. iii) System models have to be aligned to information artifacts from the models' creation onwards and standardization in exchange formats has to be ensured. iv) Information artifacts with own lifecycles shall alleviate PDM in the early product development phase. v) Interconnections shall ameliorate associativity through capturing process information between single artifacts. A first concept is presented, visualizing the aforementioned objectives and their contribution in the early development process of mechatronic products, how a permeable PDM might be achieved.

Keywords. Electric/Electronics, Model-Based Systems Engineering, Interconnections, Permeable Product Data Management, Mechatronics, Requirements Engineering

Introduction and Motivation

Due to a steady increase of variants and a higher degree of digitalization within automobiles, demands towards an IT landscape within the early phase of the product development process rise tremendously. Within roughly one decade, the number of control units in a premium middle-class car doubled [1]. This digitalization of the automobile industry partially stems from the trend towards connectivity: on the one hand the user wants to be connected with his car via smartphone; on the other hand cars shall be connected amongst each other, the so-called car2x. Additionally, more and more assistance systems, which make use of mechatronic systems, find entry to the automobile realm [2]. Mechatronic systems are the composition of mechanical, electronic and software components [3]. Within mechatronic systems, the proportional share of software advances continuously and hence yield to an augmentation of functional complexity [3]. This is demonstrated by the figure that 50 to 80% of

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innovations in the automobile industry originate from software [3]. Moreover, an ever more globalized collaboration in the development of automobiles requires interconnected workflows and employment systems [3].

The described increase of complexity in the product development process infers needs for action particularly for product data management (PDM). PDM describes the design engineering phase, including product planning and development, and is inherent to the product lifecycle management (PLM) [3]. Due to this complexity, in today's automobile industry requirements engineering (RE), model-based systems engineering (MBSE) and PDM often are separated organizationally and each domain also has its own IT-system. The impermeability between document-based RE, MBSE and PDM in today's concurrent engineering IT-landscape still constitutes a major barrier in a continuous workflow and leads to increased time and effort as well as redundancies and error-proneness [3].

This present paper aims to enrich the concept of a permeable workflow in the early phase of product development and how a consequent PDM of information artifacts supports alleviating the increased complexity in the automobile engineering, particular in the mechatronics.

Section one will deal with idiosyncrasies of mechatronic products and methods which are used in the development process. Then, based upon the idiosyncrasies and current methods in the product development process, objectives for a permeable PDM will be stated. Section two presents a first concept of artifact-oriented interconnection product documentation for mechatronic products in consideration of model-based systems engineering. Section three closes with planned further proceeding and an outlook.

1. Implications for a Permeable Product Documentation Management

1.1. Idiosyncrasies of Mechatronic Products with Regard to Product Development Process

In the last decade the amount of electric and electronic parts, control units and systems within an automobile surged [1]. As stated above, mechatronic systems today consist of electronic, mechanic and software components and underwent a transition from purely mechanic and electronic systems towards a composition also with software parts, as shown in Figure 1. To electric/electronic (E/E) parts software is not necessarily immanent, e.g. sensors and actors. Yet, control units, which coordinate amongst others sensors and actors, in a vehicle increased their importance and quantity due to an augmented relevance of connectivity and assistance systems in an automobile (cf. section 1). Therefore, this elaboration will focus on so-called "intelligent" E/E components, i.e. electronic control units (ECU) or mechatronic components.

Hence, the need for methodical process models in the product development of mechatronic products is more crucial than ever. For that reason, there is a blossoming of different methods and process models intending to handle the extreme complexity of developing mechatronic products. The most popular process model in the automobile industry with regard to the development of mechatronic products is the V-Model according to the design methodology for mechatronic systems (VDI 2206) [4].

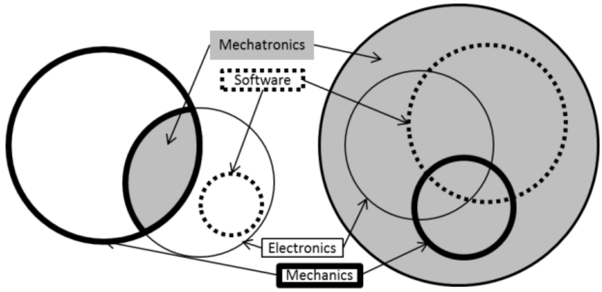

Figure 1. Transition of manufacturing engineering from yesterday (left) to tomorrow (right) (according to [3]).

Bender [5] extended the V-Model to a three-layered V-Model, addressing the different domains within mechatronic products separately. In the two upper levels, i.e. vehicle and system level, development occurs jointly. Successively, sub-systems and components are developed domain-specifically (cf. Figure 2). Precisely this separation of development in domain-specific tracks, which are often divided technically and organizationally, is what makes the development of mechatronics so challenging.

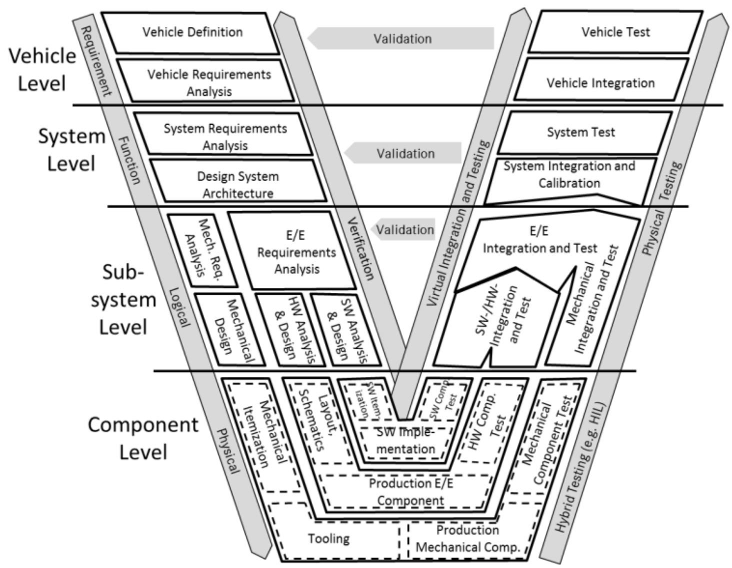

Figure 2. V-Model of mechatronic product development extended for systems development and applied to automobile development (according to [3], [5], [6]).

With regard to a permeable PDM, the idiosyncrasies of mechatronic products postulate objective i):

Capture all mechanical, electronic and software aspects which are necessary throughout the product development process to foster a permeable, model-based PDM. Identify all existing norms and elaborate how information artifacts have to be defined.

1.2. Requirements Engineering

Requirements engineering is defined by the thorough documentation of requirements of behavior, quality, and integration in a technical manner so as to assure the quality of the product and satisfy the customer's expectations prematurely. Requirements engineering is an incremental, iterative, and cooperative process targeting at the determination, analysis, understanding, and definition of requirements. Moreover, requirements management declares precise development aims to recognize and track errors and changes earlier in order to develop more efficiently. Requirements management is intrinsic to requirements engineering [3].

For the purpose of a precise description of requirements and their management during the development process, conjunct attributes are necessary. According to Eigner et al. [3], requirement attributes are determined by a name, associated semantics, and a range of values. Those attributes are assigned to categories [3]: identifiability, relations of context, aspects of documentation, aspects of content, aspects of congruence, aspects of validation, and aspects of management. Each attribute can be assigned a scheme of attribution. Schemes of attribution describe predefined and comprehensive values, such as "new", "in process", or "implemented" in case of requirements management [3].

With regard to a permeable PDM, the phase of requirements engineering postulates objective ii):

Requirements have to be designed technically and with regard to contents so that already in the early product development phase (mostly text-based) requirements can be associated to information artifacts and system models which can be used throughout the entire product lifecycle.

1.3. Model-Based Systems Engineering

A decisive impediment in the product development method of Bender [5] is that a model-based product development is not explicitly addressed. The common product development is an integrated, multi-disciplinary activity comprising all steps the product undergoes in its development (such as production, operation, and disposal) and its lifecycle to the point of supply chain [3]. Today the means of digitalization of the product development process and visualization of the results of each step of the development process is crucial for product quality and the entire product lifecycle management [7]. Therefore, the virtual product development gains more importance. For this purpose, IT-solutions are utilized in order to support and optimize the creation and documentation of work results and to ascertain that those results are available throughout the entire product lifecycle. If the description within each particular phase of the lifecycle is based upon a formal language (a formal language is an abstract language which focuses on mathematical or physical deployment [3]), digital models are built and placed at the disposal by transformation for the next phases, then the IT-process chain is denominated as model-based [3]. Hence, the model-based virtual product development (MVPD) aims at the reduction of physical prototypes by deployment of permeable, computer-supported, formal modelling and documentation. Moreover, enabling reutilization and transmission of models across all phases of the product lifecycle also is crucial to MVPD [3].

Systems engineering (SE) is defined as an inter-disciplinary, document-based approach for the development and implementation of technical and complex systems in order to assure a high-value fulfilment of stakeholders' and customers' requirements throughout the entire lifecycle [3]. Hence, SE does not solely focus on the development of a single mechatronic product, as in contrast to Bender's V-Model [5], but more on the development of complex systems which include e.g. several mechatronic components. Model-based systems engineering (MBSE), as well as MVPD, makes use of a formal language and designated system models to determine the product within the product development process in each of its phases and also in downstream processes [3]. Figure 2 already extends Bender's [5] V-Model to that effect that the different development phases for model-based systems engineering are considered: requirement, function, logical, and physical. Additionally, hybrid testing, e.g. hardware in the loop (HIL), and physical testing of model-based systems are displayed in Figure 2. However, testing is not in scope of this elaboration.

Eigner et al. ([8], [9], and [10]) present an approach how model-based systems of different disciplines can be managed throughout the entire lifecycle so that all of the time a virtual image, i.e. a so-called *digital twin*, is available. This approach is called systems lifecycle management (SysLM). SysLM depicts the information management in general which extends common product lifecycle management (PLM) by an explicit consideration of upstream and downstream phases of development [8]. Therefore, all disciplines are in scope. The PLM backbone shall incorporate the entire system lifecycle management [8].

Gilz [11] describes a method for integration of discipline-specific MBSE data in a PLM backbone by usage of a functional product description (FDP). Functions are common information artifacts in an interdisciplinary context. The main artifacts of the FDP are: system requirements, system functions, logical system elements, and physical system elements [11]. Gilz [11] further highlights in his outlook the need for a combination of system models and configuration as well as variant models.

With regard to a permeable PDM, the concept of model-based systems engineering postulates objective iii):

System models have to be aligned to information artifacts from the models' creation onwards throughout their entire lifecycle (systems lifecycle management).Permeability between IT-systems and development domains has to be ensured.

1.4. Artifact-Orientation and Product Data Management

In software development, the need for efficiency enhancements with regard to reutilization of previously developed so-called components is nothing new [12]. By means of those components, small- or large-scale software can be composed by reusing the previously developed software objects. Due to object and component have different meanings concerning which domain is in scope, the terminology *artifact* will further on depict a piece of information with a unique identifier within IT-systems in the virtual product development process. For the distinction of objects and components in software development see Brown [12]. Moreover, a component in automobile industry commonly refers to a mechanical element or part which fulfills a dedicated purpose in an automobile. However, even within one company there exist a plethora of different meanings of a component [13]. Hence, the terminology artifact is chosen in order to distinguish from sole software development and from the term mechanical component which usually is used in automobile industry. Public team data management (TDM) and PDM software implements an innovative technique using single software artifacts which can be managed independently throughout the entire lifecycle of ship development and production [14]. Each artifact has its own lifecycle with its revisions and status which is not limited by an assembly item's lifecycle. Hence, isolated revisions and change management of each artifact within a product is feasible, apart from the assembly [14]. Additionally, [14] depicts that so-called collaborative designs, e.g. a certain ship model, can be defined company-wide. Partitions, intrinsic to the collaborative design, represent a structural breakdown of the product and can be formed manually or via recipe rules. Partitions are formed by different artifacts, which are linked to the corresponding partition, and display the traditional hierarchical view of an engineering bill of material (E-BOM) [14]. Partitions are separated into functional (e.g. different (mechanical) systems for different purposes), spatial (e.g. different zones of the final product), and physical (e.g. part *x*). Data representation in the artifact-oriented PDM is semi-non-hierarchical, i.e. artifacts are stored in a vault and managed separately (see above). However, for purposes of usability, collaborative designs are defined but artifacts have no specific structural position; hence, the non-existence of hierarchy is partially diluted, i.e. "semi-non-hierarchical". Conversely, traditional PDM systems have a single, semi-flexible hierarchical product structure due to a configurable structure level-by-level. This single, semi-flexible hierarchical product structure is comparable to a book library, because books are retrieved from a shelf and returned to the same shelf, as well as products are loaded out of a BOM structure and returned at the exact same position during development. Artifact-oriented PDM incorporates recipe rules for product variant structuring which is similar to traditional, hierarchical PDM systems. Both use Boolean algebra to create code conditions in order to in- or exclude further configuration options, such as partitions, modules, etc. [14].

With regard to a permeable PDM, the concept of artifact-oriented PDM postulates objective iv):

Information artifacts shall alleviate handling complexity in the early product development process by owning their own attributes and lifecycle. Specific designs, e.g. collaborative, functional, spatial, and physical, are generated by combination of single artifacts. Artifacts shall be managed in a common PLM backbone.

1.5. Interconnections

The concept of artifact-oriented PDM and traditional, i.e. hierarchical, PDM use recipe rules, based upon Boolean algebra, for product and variant configuration. In hierarchical product structures products still are depicted as a sum of single parts. Furthermore, structural associativity between parts and assemblies are, if at all, only limited represented in traditional PDM. The Boolean algebra codes can mutually exclude components within an assembly. However, management information between components on the same structural level are not provided [15]. This deficit of associativity between components on the same level, in case of traditional PDM, stems from the fact that structural togetherness mainly is described through parent-child relationships between assemblies and their intrinsic components in the form of "is part of" or "belongs to". Interconnections mitigate this issue by describing a product as parts and interconnections in a web to enable an integrated product model (cf. Figure 3) [15]. This allows for an overview which captures all elements with their structural associativity, comparable to a systems view (cf. section 1.3.). In comparison to the artifact-oriented PDM method with a semi-non-hierarchical product structure, interconnections yield no further advantage with respect to product decomposition and structure. Yet, interconnections also comprise process information, such as tooling, assembly order or factory planning. For this reason, the concept of interconnections can describe more lifecycle phases than the artifact-oriented method which only limitedly includes tooling and factory planning. A drawback of the interconnections documentation is that it cannot consider computer-aided design (CAD) because it only describes the lowermost component decomposed in its parts and interconnections.

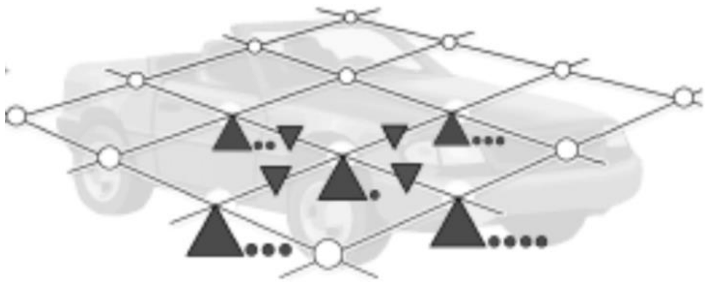

Figure 3. Interconnection product structure decomposition [15].

With regard to a permeable PDM, the concept of interconnections postulates objective v):

Ameliorate information for associativity through process information captured in interconnections between single artifacts. Interconnections shall mitigate disruptions between requirements engineering, model-based systems engineering and product data management by providing additional insights in systems and their associativity.

2. Approach to the creation of a concept

Information artifacts, already generated in the requirements engineering (RE) phase, will be used in this elaboration to address the issue of continuous and permeable product documentation (cf. section 1.2 and 1.4). During RE phase, artifacts are associated (*scope*, displayed by the crosshairs in Figure 4) with the first drafts of vehicle outlines, e.g. architecture (see Figure 4). Besides, access regularities for development engineers are defined (displayed by the lock in Figure 4).

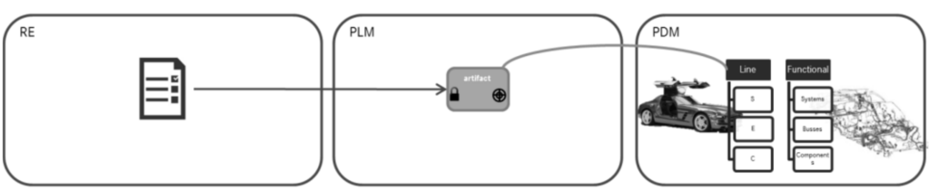

Figure 4. Associativity of information artifacts in requirements phase.

Those information artifacts each are deposited independently in a multidisciplinary repository, containing different, specific attributes regarding their lifecycle, access authorization, geometric position, and configuration range (cf. section 1.4). Model-based systems engineering engages those previously defined artifacts, which have been enriched with further information, and simulates the interaction of the components in their specific system and for their specific purpose, e.g. within a computer-aided software engineering model, simulation model, manufacturing computer-aided design (CAD) model, electronic CAD model, and the overall system model, which depicts the interdependency between the single models and their global functionality, as depicted in Figure 5 (cf. section 1.3).

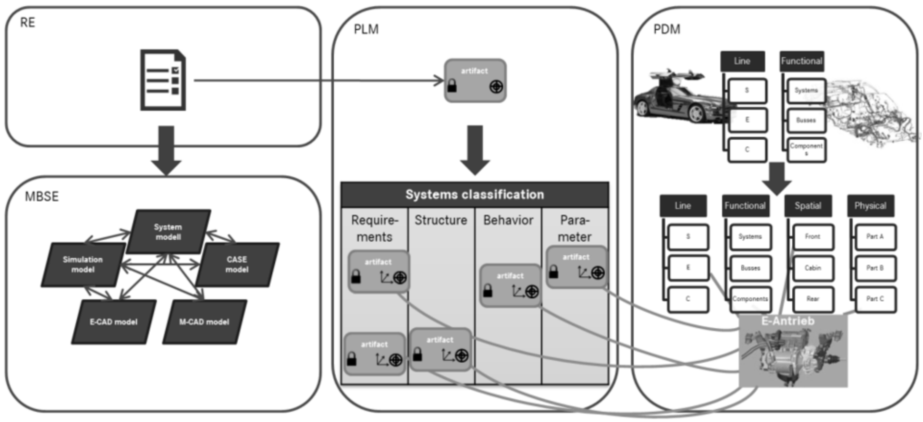

Figure 5. Associativity of information artifacts in model-based systems engineering phase.

Via interconnections, immanent linkages that incorporate further qualitative and quantitative product- and process-related information, simulation models, structural breakdowns and views, as well as information artifacts are associated to each other (cf. section 1.5). Hence, a reutilization in following simulations can be indemnified without re-specification. In the PDM, a semi-hierarchical product structure and an ad-hoc, user-specific representation given the individual purpose, mitigate documentation complexity and effort (cf. section 1.4). Therefore, information artifacts are associated through interconnections to multiple physical components, as well as directly to functional systems, spatial divisions of vehicles or entire model lines (cf. section 1.5). Each engineer administers the information artifacts in the multidisciplinary repository, which therefore functions as a single source where also variant and configuration management takes place (cf. section 1.3 and 1.4). Multidisciplinary repository, single source, and PLM backbone are used as synonyms. Whenever a new vehicle is created, the already pre-defined information artifacts in the PLM backbone can be deployed to be re-associated to this new vehicle without entire re-development, as depicted in Figure 6.

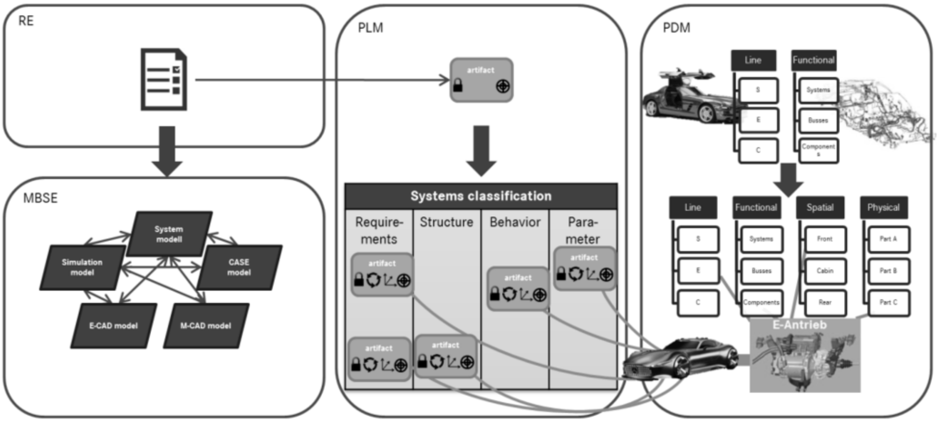

Figure 6. Re-utilization of pre-defined artifacts for a new vehicle.

The target situation is shown in Figure 7. Objective i) would be addressed inherently by the design of information artifacts. Objective ii) is captured in the RE phase whereas objective iii) is also already pre-defined in the RE phase and further specified during the dedicated MBSE phase. Objective iv) has to be taken into consideration throughout the entire conceptual work, particularly with regard to the PLM backbone and requirements stemming from discipline specific designs and partitions in the PDM system. Objective v) is crucial for the linkage of MBSE, PLM, and PDM. Moreover, objective v) supports an improved allocation of artifacts in their specific destination, e.g. interconnected with a system, a spatial area, or a physical component.

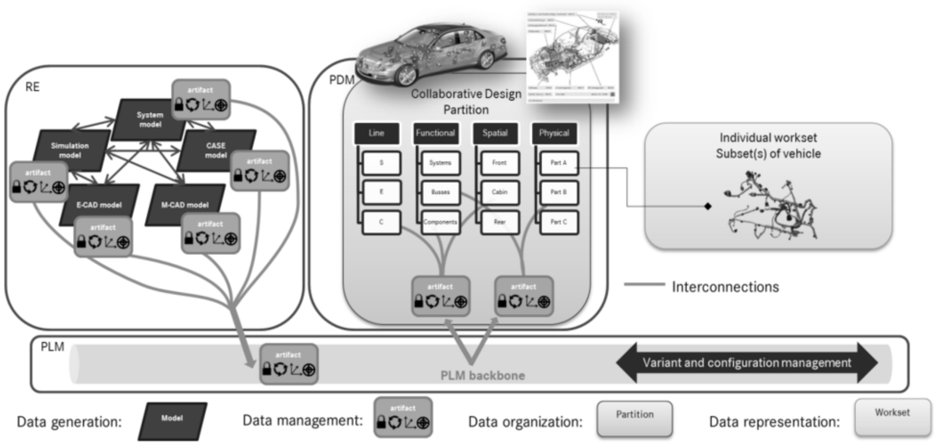

Figure 7. Conceptual target situation of artifact-oriented interconnection product documentation in consideration of model-based systems engineering.

3. Outlook

Due to being a conceptual paper, there is still a lot to consider. However, the main theories have been highlighted and also which objectives stem from them with regard to artifact-oriented interconnection product documentation for mechatronic products in consideration of model-based systems engineering. Additionally, state of the art norms, methods, and concepts related to each presented phase and method of product development have to been observed. According to [16], further literature research has to be conducted to additionally clarify the research questions. Then, an empirical data analysis follows, e.g. a stakeholder rally. This is the descriptive study 1 and it fosters the understanding by building a reference model and defines success criteria. Afterwards, assumptions, experiences, and synthesis form the prescriptive study which results in an impact model and support evaluation. The descriptive study 2 uses real data in order to evaluate the impact model's success and predict further implications.

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Scope Patterns for Projects Modeled as Sociotechnical Systems

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Abstract. This paper examines the treatment of scope as project attribute, arguing that an improved representation will allow increased fidelity of project plan trade space enumeration and preferred plan selection. Cost, schedule, and scope are emergent characteristics of a project's integrated architecture, activities, and resources uniquely for a project at hand. System engineering as commonly practiced places strong, early emphasis on product architecture and requirements, including enumeration of system options prior to interplay with aspects of project implementation. As such, system options are often framed and pruned prior to effective examination of project feasibility. Characteristics of scope are presented suitable for model-based design of projects. Scope is defined as the tangible outcomes of project tasks. Scope items should be useful in the evolution of project knowledge and interplay with requirements and resources. Target-neutral, resource-nominal, and exception-capable patterns of scope are described.

Keywords. Model-based systems engineering, scope, triple constraint, scope patterns, sociotechnical systems, project design, MBPD

Introduction

In engineering much attention has been given to consideration of stakeholder needs and their relationship to product requirements. In best practice, these requirements are written as solution neutral, so that a trade space of product solution alternatives may be enumerated prior to generation and evaluation of options, unbiased by prior assumptions [1].

Typically, a similar neutrality is not maintained for consideration of *project* alternatives. On the contrary, upon selection of architectural options it is common to determine the utility of product system alternatives prior to consideration of resource and other implementation issues. *How* the system is to be implemented is considered a separate analysis from *what* the system should be. In those cases where feasibility is considered, assumptions of likely implementation reply upon historically based process cost, schedule and quality or a notional standard work. Deeps assumptions from a century of scientific management reinforce this reliance upon implementation as operational repetition with low variation [2].

We have seen therefore the enumeration of product system trade spaces without interplay with project options, thus biasing and pruning alternatives prior to effective examination of feasibility. An optimal system architecture and technical approach is

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selected, yet later to be discovered infeasible within cost, schedule and quality implementation constraints. Given complex organizations and the burden of document-based workflow this separation has been understandable. With the extension of model-based systems engineering (MBSE) to the design of projects, an opportunity is presented to concurrently retain options both desirable and feasible. *The product system and project system should be designed together*.

In the development of model-based project design (MBPD), this paper explores a definition of scope useful in project models. When viewing a project as a sociotechnical system, cost, schedule, and quality are emergent characteristics of the scope, resources, and architecture, often unique to the project at hand [3]. In the spirit of concurrent engineering, both product and project systems alternatives should be retained until sufficient knowledge is gained through investigation and decisions.

This paper focuses on characteristics of project scope, an attribute of a project model with useful evolution and interplay with other project attributes. Examples of target-neutral, resource-nominal, and exception realistic patterns of scope are shown. This approach improves comparison of scope across projects and enables more realistic forecasting at the start and as a project changes.

This paper begins with a review of related research, introduces a definition of project scope suitable for model-based project management, describes characteristics of scope units and patterns, and discusses several examples. The paper concludes with known limitations and next steps in this research.

1. Conventional Representations of Scope

A review of related literature shows a wide range of uses of the term "scope" in project management. Most commonly scope refers to the boundaries and content of a project: what work is included and what work is not included. However, *scope* varyingly refers to project targets, requirements, processes, deliverables, resources, and even milestones and schedule dates. Based on this wide range of interpretations, one could conclude that the scope IS the project, rather than one aspect or dimension of the project.

1.1. Project Management Standards and Practices

Let's begin with the standard definition from the PMI's Project Management Body of Knowledge (PMBOK): "Project scope. The work that needs to be accomplished to deliver a product, service, or result with the specified features and functions" [4]. Given this definition, several interpretations are reasonable in practice. Does scope refer to work as process, the outcome of tasks, or even the architecture of the project? Is scope the project work itself or the activities related to managing the project? What attributes of a project are not an aspect of scope?

Even within the PMBOK other references to scope and scope management are inconsistent. Scope management is defined to include "the project and product requirements, criteria, assumptions, constraints, and other influences related to a project, and how each will be managed." Here one can see an expansive definition that would seem to include everything both internal to and influencing a project. This language in PMBOK is readily copied throughout the internet and practice; a simple internet search shows language about scope management repeated over and over, yet applied diversely. Many follow-this pattern consistent with PMBOK: claiming the importance of scope definition and management, providing an expansive but in the end inconclusive definition [5].

Experience in the field with complex engineering projects bears out this confusion. Very often dysfunctional dialogue amongst key teams during design and implementation is rooted in misplaced uncertainty and misalignment given different understanding of scope in the project. If one is to include scope as an attribute in a project model, a more specific definition of scope is needed.

1.2. Scope as Part of the Triple Constraint

In practice, and across various standards, scope is referred to as one of three dimensions of a project to be managed: scope, cost and schedule. As a project is planned and managed over time, these three dimensions are coupled: at some point the increase in scope will impact cost or schedule, and so on. Informally these three dimensions are also referred to as the *iron triangle*, in that once a project has been optimized in may not be feasible to improve all three dimensions at the same time. More recent versions of PMBOK have expanded the original triple constraint with three more elements: Scope, Quality, Schedule, Budget, Resources, and Risk.

Lee-Kelley, pointing to the well-known Handbook of Project Management by Turner [6], referred to scope as one of five dimensions of a project, along with organization, cost, time, and quality. Consistent with the broader usage the author wrote “the scope of the project demarcates its work boundary and is managed through the product and work breakdown, which are derived from a ‘hierarchy’ of objectives from ‘vision, mission, facility, team and individual objectives" [7]. Lee-Kelley proceeded though to refer to scope without formal definition, implying that scope is a measure of the project duration, team size, and skills required. As in other references, “scope” seems to act a stand in for many aspects of a project.

Across these approaches, whether scope is one of three, five, or six dimensions of the project, an underlying premise is that scope is not the same as these other dimensions, especially cost and schedule.

1.3. Task Estimation based on Interplay of Scope and Resources

Others have considered the nature of scope in order to estimate task size. Brooks famously argued that use of *man-month* as a unit for measurement of the size of a job is “dangerous”. He wrote that “Man and months are interchangeable commodities only when a task can be partitioned among many workers with no communication among them”[8]. Brooks added that traditional estimates also ignore the likely yet unexpected difficulties in execution. Importantly, when considering scope Brooks weighs the nature of particular kinds of activities specific to software development, rather than generic tasks of fixed duration, and suggests estimation based on these characteristics while avoiding linear extrapolation of small, task-local estimates to larger projects.

Similar to Brook's mythical man-month, Lanigan exposed the fallacy of estimation without considering both the nature of the task and the characteristic of resources [9]. Lanigan proposed characterization of a task’s scope with nominal effort description of the task including a minimal team size, beyond which linear extrapolation would not make sense.

Rodriguez empirically explored the trade-off of team size and productivity for software projects [10]. Based on a large data set of benchmarked I.T. projects, the research objective was to uncover productivity trends by scoring the scope and effort of these projects. They attempted to derive concrete units of scope from overall project sizing and count of designed units or function points, and productivity as function points per staff hour. Results were consistent with a premise that teams of nine or more have diminishing returns in productivity.

Holtta-Alto and Magee explored human resource utilization in product development projects across several sectors. They found that for large projects resource factors are often masked since estimation is conducted at a higher level. They also pointed out that for many estimation approaches rarely are interactions taken into account [11]. Both Holtta-Alto and Rodriguez point out the insufficiency of typical methods which rely on data from past projects which resource issues, interactions, and strife with missing values and errors.

1.4. Complexity, Readiness, and Standard Units

Clark in 1989 referred to project scope in product development as an aspect of strategy: the amount of new content developed in-house. A project with off the shelf mature parts is described as having less scope than a project with parts that require new and uncertain development efforts. Parts that are outsourced to suppliers might require the supplier to engage in more scope, yet that scope is outside the boundary of the project as defined in Clark's representation [12].

In addition to the degree of new content, some industries manage projects which require larger commitments prior to starting and significant risks of changes. In these industries an increase in planning to determine scope offsets downstream consequences of getting scope wrong.

The Product Definition Readiness Index (PDRI) was developed in the 1990s by the Construction Industry Institute (CII) to improved scope definition in capital projects. While PDRI is weighted scorecard to audit the readiness of a capital program to proceed to a major gateway, PDRI covers more than scope. The scorecard includes a broad range of items for readiness including strategy, requirements, site information, procurement processes, equipment, resources, control, risks, and so on. Therefore, PDRI -- even though described as a scope management tool -- refers to the readiness of the entire project for implementation, consistent with a broad definition of scope as project. Other than the long list of items in PDRI, a clear definition of "project scope", however, is not given [13] [14].

A recent approach to scope for the construction industry was proposed by Song [15], named the quantitative engineering project scope definition (QEPSD). Their paper describes scope as "subdividing the overall project deliverables into smaller and more manageable components, resulting in better project planning and control." They report that in construction projects previously scope could have been estimated by the number of design documents for each functional area. However, due to the shift to digital (CAD models) for the as-built environment these measures are no longer relevant. Instead Song recommends units more closely tied to physical design deliverables, referred to as "design items" in functional terms, adjusted for complexity. Within a functional area, for example structural steel, the discipline should define standard units as an abstract measure against which specific jobs can be compared.

These authors repeat a common caution from those relying on past data in studies: many corporations have tracked progress as aggregate measures of staff hours against account codes as a stand in for scope. Similar to arguments against EVMS, the existing data available was leveraged as a stand in for broader project characteristics, requiring heavy assumptions leading to inaccurate understanding of these non-cost related characteristics. These past cost or effort data alone should not be confused with scope.

2. Scope

By review of related literature, we can see that the term *scope* has been used broadly, with intermingling of ideas relevant to project targets, requirements, resources, architecture, and cost/schedule. We ask, at what point is the characteristic an aspect of scope rather than an aspect of value, of resources, or of architecture? How can we describe the scope so that resources can be matched, yet not presume what the specific resource will be? If we change non-scope characteristics in a project, yet leave scope the same, will a change in total project outcomes be observable? If team characteristics vary, will the scope characteristics still be valid and useful?

A useful definition of scope should stand regardless of the number of resources or duration of the project. Scope should be defined so that scope, as it exists, might be valued differently by various stakeholders. A working definition for this paper is centered on deliverables rather than process or architecture:

- **Scope is the tangible outcome of project tasks.**

Further, it is argued that scope exists (at some quality) at the conclusion of work. Scope drives cost and schedule, but is not cost and schedule. Scope is evaluated against requirements. The same scope, in different stakeholder context, may have different value. Resources may be required, but the amount of resources used does not change the scope. Scope includes intermediate deliverables necessary to achieve requirements in ultimate project output, including repeated scope due to rework.

Scope helps to clarify the boundaries of a project: <u>what</u> scope will be completed during the project. (Therefore, also what scope will not be included.)

2.1. The Zen of Scope

- Scope is.
- Scope isn't value, but it's existence is a basis of value.
- Scope isn't work, but is the result of work.
- It **is**.

2.2. Scope Items and their Attributes

A project's scope element as a tangible outcome of a work task will be described so that the item can be planned, designed, implemented, and evaluated. Our research on project activity modeling, starting in 1995 at the University of Tokyo, has emphasized scope as generating a demand for activity. Project models are used to forecast the realization of scope. The scope of each task is characterized by units, effort, and complexity [16] .

- **Units**. A dimension of measurement for the expected deliverable or outcome, relevant to the teams who hold domain knowledge and will be involved directly in realization of the scope. Drawings, Parts, Prototypes, Tests, Sites, Reviews, etc. These scope units are useful so that scope will be monitored. Audited. Tested. Accepted. Received. In some cases, these units of scope, by their nature (not a characteristic of project targets nor resources) are divisible during the flow of work. In other cases, the delivery of units by their nature must be as a set or in a continuous stream.

- **Effort.** Effort in nominal hours is used to describe the size of the items in comparison to a standard case. Nominal effort is not a measure of a particular team and resource, but rather a measure of the scope. See "Resource Nominal" below.
- **Complexity**. The degree of needed information, and therefore uncertainty, required to realize the scope. More complex scope requires more information to be realized. The complexity measure corresponds to the proportion of coordination activity to nominal work activity required to transfer the scope across dependencies.

Over sixteen years across many industrial workshops we have found the capture of scope in project models to be practical if the representation follows three principles: target neutral, resource nominal, and exception realistic.

2.2.1. Target Neutral

Scope items should be represented independently of any targets for the scope's realization and how the scope will be valued. For example, if a planned scope is 24 drawings, the actual scope generated is 27 drawings, these plans and actual drawings exist whether or not the target was 20 or 30 drawings. (It can be true that a plan does not meet all targets, and that actual results might not meet a plan). If project objectives change, and thus targets and how they are valued, the scope (drawings) still exists as planned and as implemented.

2.2.2. Resource Nominal

The scale of scope items can be described in comparison to a commonly held view of typical resource requirements. In other words, the scope be represented as resource nominal: given a starting point assumption of the typical, nominal team size, what is the effort of the scope?

- **Nominal** scope: a measure of the amount of output driven by **work at a common unit of resource**
  - # Stories in a day for one experienced (and uninterrupted) professional
  - # Bricks by a single average bricklayer in a day
  - Man-months

Consistent with Brooks, the assumptions of valid linearity of effort to resource availability can be stated as an inherent characteristic of the scope. Resource nominal scope is a basis of dialogue, not only for deliverables but also to anchor a description of scope and information flow across dependencies.

2.2.3. Exception Realistic

Scope should be represented so that imperfect implementation and rework can be modelled. In some cases, the failure of teams to allocate attention in a timely manner will lead to errors, and in turn the imperfect scope will be either reworked or not, in turn leading to system consequences. Therefore, the state of the scope item should include completeness and quality.

3. Scope Patterns

Scope Patterns are sets of scope items that share common characteristics including units, association to nominal effort, complexity, and exceptions. Scope patterns easily fit to the way that certain working teams think about, discuss, plan, and monitor work. These patterns are defined to meet the characteristics above: target neutral, resource nominal, and exception realistic items. These patterns allow an essential, abstract definition of the nature of the demanded work, more easily defined downstream as details of the scope are learned. Several examples of scope patterns are shown in the table below.

Table 1. Scope Pattern Examples.

Fixed Duration	The scope is demanded from the start milestone and the demand stops at a fixed duration after that start. The completeness and quality of the scope might be effected if attention and resources are not sufficiently supplied during the fixed duration. This pattern is the historical basis of most planning models and forecasts, including CPM, PERT etc.
Linear Burn Down	A demand for scope exists at the start of activity. As resources apply attention the scope is generated; the more attention and skill the faster the completion of the scope. With poor supply of attention and mistakes, the duration might extend or poor quality is accepted (if visible). Common in agile software projects.
Units non-linear Effort	Scope is described by units, yet units are not of common nominal effort. Overall progress is non-linear depending on which units are selected for attention by resources. Sometimes this non-linearity is captured by having a subcategory of units; 24 drawings, 5 of which are assembly, 10 are large parts, and 9 are small parts. Common in complex engineering projects.
Map Coverage	Scope is defined by work across a map or range; attention to an area within the range allows for completion of that portion of the scope. Feasible pathways within the map may be an inherent aspect of scope. A common pattern in infrastructure projects.
Cyclical Operations	Demand for progress is limited to a period which repeats; unattended demand may be removed, rolled over, and/or a driver of poor quality and rework. Within a period (e.g. a week, a month) the progress on scope might be similar to other patterns. Common in the administrative activities of most projects.

4. Comparison of Project Performance by Scope

It is common to evaluate the performance of projects by comparing a given project to others, with differences in scope, resources, architecture, and externalities taken into account. By describing scope as resource neutral, various resourcing options can be compared both during planning, but also in comparing project of similar scope across past actual results. In this case one should differentiate clearly between nominal scope and actual scope:

- **Nominal scope**: does not count repeat (whether intentional or rework) if these could be avoided in different project scenario of same scope.
- **Actual scope**: the total output as actually generated, including poor quality, excess quality, mistakes, and repeats

5. Conclusion

This paper has presented a definition and example uses for scope in projects. Projects are considered sociotechnical systems, therefore the cost, duration, and quality of tasks are an emergent result, influenced both by the underlying characteristics of the task activity and the position of the task in the project architecture. As such, a definition of scope is presented so that these task dynamics can be modeled, simulated, and therefore the designed. Scope is the tangible outcome of tasks, represented independently from project targets and resources. So that the project scope can be considered in combination with other project elements, the scope is modeled to be target neutral, resource nominal, and exception realistic.

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Colleagues working to develop and deploy *Project Design* workshops over the last sixteen years have helped to evolve this thinking about scope and its practical application in the design of complex engineering projects. Special thanks to Ralph Wood and Roland de Filippi.

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Simplified Informational Design Steps for Micro and Small Companies

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Abstract. Micro and Small Companies (MSC's) have an important role in world's economy, despite the challenges they face. One of them is the absence of adequate human resources and formal work procedures as the New Product Development Process (NPDP). This fact is critical for its competitiveness with large ones, who have some repertoire and elasticity while addressing the critical user needs. This work aims to propose a simplified procedure to address informational design in MSC's. It was based on a comparative study between four traditional NPDP models and formalized into a didactic bundle, consisting of Excel Sheets. It was applied in a pilot experiment within a Small Company and the designers' opinions were collected through a questionnaire. The effect of the proposal was checked past 18 months, with an interview. The manager reported, despite the benefits perceived with the training, they still do not apply any kind of NPDP methodology in the company. Nevertheless, he concluded that a regular presence of a consultant would be required to change the situation.

Keywords. New Product Development Process, Micro and Small Companies, Informational Design, Early Stages

Introduction

According to the Brazilian Support Service for Micro and Small Enterprises (SEBRAE) in Brazil there are over 6 million of micro, small and medium enterprises, which contribute to 25% of the Gross Domestic Product (GDP), and are responsible for more than 50% of formal employment. But his participation in the economy could be higher, considering that 31% of companies do not exceed the first year of activity [1]. Micro businesses are those with up to 19 employees (industry) and gross annual income from R$ 60,000.00 to R$ 360,000.00, and small businesses are those with 20-99 employees (industry) and annual gross income from R$ 360,000.00 to R$ 3.6 million [1]. These companies also have been financially stimulated to innovate: in 2014 the Brazilian Development Bank (BNDES) released R$ 500 million for innovative companies [2].

However, many still do not have their processes formalized. According to Inmetro's research [3], 55.7% of Brazilian companies do not have the ISO 9000 (quality management), being 66.7% of this percentage the Micro and Small Enterprises (MSEs). According to Rozenfeld *et al.* [4] the New Product Development Process (NPDP) formalization is an important factor to the projects quality. Thus, it can be said

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that the absence of ISO reflects the lack of organization of this and many other processes at these companies.

According to Rozenfeld *et al.* [4], the alternative decisions at the beginning of the NPD cycle are responsible for 85% of the cost of the final product. The cost to modify new product features increases over NPD cycle because, at every change, a greater number of decisions already taken can be invalidated. Therefore, giving importance to early stages of the NPD minimizes failures during subsequent stages, and can stimulate the final product quality acceptance.

The data set presented above demonstrates the MSCs importance in the country development and the adequate NPD methodology application, especially in the early stages within these companies. Based on information gathered on the NPD in MSCs, the purpose of this article is to develop a guide containing the basic steps of the early stages of the NPD on a simplified way, which can be applied easily in any MSC. This aims at helping to greater understanding of the NPDP concepts and to stimulate their practice.

1. Research Methodology

The study began with a search in Google Scholar websites and Capes Periodic Portal (www.periodicos.capes) in order to verify that the issue had already been addressed in other works.

The combinations of keywords used were: development, product, micro, small business; development, product, MSC; and MSC, initial stages, NPDP. As the search did not shown any specific NPDP model for MSCs, the next step was the taxonomy based on the early stages of four traditional NPDP models: Rozenfeld *et al.* [4], Pahl *et al.* [5], Back *et al.* [6], and Back and Forcellini [7]. These steps were compared and the most cited activities were selected, assuming that these similar steps would be paramount to the early stages. Thus, they have been detailed and compound the suggested set for use in MSCs. From these steps, a courseware was made for training, consisting of six forms built in spreadsheets. To validate this proposal the steps were presented in a pilot company and the designers' opinions were collected through a questionnaire.

2. Product Development in Micro and Small Enterprises

2.1. Early Stages of the Product Development Process

In the NPDP there are activities ranging from the generation of design specifications to the preparation of documentation required for production [4]. Much of the important decisions taken for the project are made in the early stages, where the degree of uncertainty is higher [5].

The objective of this stage is to develop a set of information called the product-target specifications, which define the roles and the required product properties. In addition to direct the solutions generation, they provide the basis on which are set the evaluation criteria to the decision making in the later stages. [7]. No relevant information was found related specifically to the initial phase of the product development process in micro and small businesses. It is believed that situation is due to the current informal NPDP management, as shown and concluded in the introduction.

2.2. Informational Design Activities Taxonomy

Table 1 contains the steps suggested by the authors Rozenfeld et al. [4] Pahl et al. [5] Back et al. [6], and Back and Forcellini [7] to the early stages of the NPDP.

Table 1. Comparative between early stages of the NPDP.

Rozenfeld *et al.* [4]	Pahl *et al.* [5]	Back *et al.* [6]	Back e Forcellini [7]
Update the Informational Design Plan.	Detailing life cycle, elaborate product/market matrix, identifying own competence x competitors, technology search and evaluate future developments.	Present the project documentation plan and system.	Search relevant project information.
Review/update the product scope, analyzing the design problem, technologies, standards, patents, legislation and the like.	Identify strategic opportunities, demands/trends, consider business objectives and determine the search fields.	Research development to define influence factors, monitor market demands, users definition and research.	Set customers throughout the life cycle and collect your needs.
Detailing the product life cycle and set the project clients.	Get ideas for the product.	Unfold needs / requirements, valuing them and establishing requirements/ specifications.	Establish customer requirements.
Identify requirements gathering, grouping, sorting and valuing their needs.	Select product ideas.	Set influencing factors in the manufacturing plan.	Estabelecer os requisitos do projeto.
Define product requirements, converting them into measurable expressions, analyzing, classifying and ranking.	Set products, specifying ideas and defining project requirements.	Search security throughout the life cycle.	Prioritize project requirements.
Define product-target specifications, valuing the requirements, analyzing technical and market profile and analyzing project restrictions.		Set the dependability goals and target costing of the product. Carry out economic and financial analysis.	Establish design specifications.
Monitor the economic and financial viability.		Evaluate design specifications and approve them	
Evaluate the phase gate using the criteria of the information design phase.		Update the project plan and fill the passing phase of approval form.	
Approve phase, evaluating the criteria of the previous step and comparing with other portfolio products.			
Documenting the decisions made and lessons learned.			

The research activity is one of the initial steps in all methodologies, also the informational design plan update [4] and the plan presentation and project documentation system update [6]. An analysis of the situation at the start of product planning is taken, and the product lifecycle is identified, as sub-step [7]. Steps involving product lifecycle appear along all methodologies, only on Back et al. [6] it appears after the requirements establishment step. Product requirements definition steps appear on the 3rd, 4th and 5th positions in the methodology, except in Back et al. [6], which come before the definition, approval and documentation of results steps, or follow the economic and financial accompaniment step ([4]and [6]). One can sort the methodology of Back et al. [6] as being with more steps and requiring greater involvement of the company. Pahl et al. [5] can be seen as the most direct, with steps already focused on generating ideas.

2.3. The Pilot Company and the Adventure Clothing/Equipment Sector

The pilot company, based in Campo Largo City, Paraná State, Brazil, was founded in 1990 and is categorized as small business (64 employees and annual revenues of R$ 639,000.00).

The company has a product development team composed by the manager/owner and two people working exclusively with the clothing line. The adventure equipment line is developed only by the owner, who has a 25 years experience of climbing. In the the actual NPDP usually some existing model from the comptetitors is taken and then the details and changes are defined. Quickly a pilot piece is made, which often undergoes changes. When the products involve security they are sent for a certification and testing laboratory, if not they are sent for a test team (sponsored athletes). With the exception of some parts, produced in Italy, the manufacturing system is national and made up of production cells (factions) who work exclusively for the company.

2.4. Similar and Related Works

Twelve similar works were met, although indirectly related to the problems outlined here.

Terence [8] discussed the strategic planning as a competitive tool in small business, and prepared a script based on planning models proposed by the authors of the area.

Oliveira [9] has formulated guidelines to support technological innovation in product development in small and medium industrial enterprises. The author presented tables with the development guidelines, separated by the ripening stage of SMEs in each technological innovation factor. Despites very complete, this ended up with a complex model.

Souza and Abiko [10] created a methodology to improve the development and implementation of quality management systems in small and medium construction companies, based on ISO 9000 standards.

Gonçalves [11] discussed the implementation of Quality Management in a small company through action research, addressing planning and actions relevant to the business, especially the characteristics of the process of product development, the performance measurement system and scheme for continuous improvement.

Scoralick [12] characterizes the NPDP in small technology-based companies. The work comprises a bibliographic study of product development management, a discussion of the companies and their innovation process and a small case study. Important tools were used for the NPDP but did not consider the constraints of MSCs.

Carajiliascov Son and Katko [13] present a Competitive Intelligence System (CIS) for a small company in the metallurgical sector, proposing an ongoing project of knowledge management. Tools and concepts have been used to target the company's organizational improvement in its entirety and demands greater financial commitment, as it requires hiring of skilled labor and mobilization of all sectors of the company.

None of these works aims at a simple early stage NPDP guide for MSCs.

3. Simplified Informational Design Steps for MSCs

All the steps founded on the taxonomy can be grouped on six steps with common appearance in the surveyed methodologies. They are:

1. Searching for information of existing products: survey of design theme, similar projects benchmark, current technology, trends;
2. Customer needs assessment in the product life cycle: defining the stages through which the product pass and the customer needs of each stage.
3. Qualification of the target audience's needs: to organize hierarchically the most and least important needs for the customer;
4. Generation of requirements based on the needs raised, turning them into measurable requirements for the project;
5. Valuation of requirements: using tools, which in many cases is usually the House of Quality (QFD - Quality Function Deployment);
6. Drawing up the list of project-target specifications, organized in a ranking of importance.

The application of the steps was through teaching materials composed of six forms, one for each step, who must be filled in digital form, with the exception of the form 3, which should be applied as a questionnaire survey of the company's customers.

3.1. Tools and templates presented to the Pilot Company

As an ilustrative example to the Pilot Company, a headlamp was used as a tool template. All the files used can be obtained with the authors.

The first step consist of a research aimed to produce a comparative table with competition products benchmarking (Table 1).

Table 2. Step 1 Tool - Excerpt.

Criteria	Model 1	Model 2	Model 3
Brand	Petzl	Petzl	Black Diamond
Characteristics	High performance, rechargeable batteries	Versatile, high battery life	Lightweight and compact
Image			
Applicable standard	Does not have	Does not have	Does not have
Weaknesses	High cost	Large	Little tough, low light
…	…	…	…

The MSCs need to define the comparative criteria which most reflects its interests. This table is better developed collaborativelly and when finished may be shared internally.

The second step involves que customer needs assessment in the product life cycle (Table 3).

Table 3. Step 2 Tool – Excerpt.

Life cycle	Internal customer (company itself - you)	Intermediary customer (distributor - retailer)	External customer (end user - buyer)
Project	Few parts, low production cost	-	-
Manufacture	Using standardized materials	-	-
Assembly/ Packing	Using standardized processes	-	-
Storage	Having compact package	Being compact	Having strap to hang
Transport	Having resistant packaging	Being light	Having resistant material
Sale	Look good	Having low price for consumers	-
Purchase	-	Having product information in the package	Having transparent packaging
...	...	...	…

As can be seen the need must be raised considering three principal customers along the product live cycle. A good product must balance those needs.

The third step involves the classification of the target audience needs, where the raised needs are prioritized according to importance. The tool for this step is the needs table generated in the previous step, with fields to grade the importance of each one (Table 4).

Table 4. Step 3 Tool – Excerpt – Just the internal customer needs.

Internal client needs	Importance degree			
	5	**3**	**1**	**0**
Having few parts		X		
Having low cost of production		X		
Using standardized materials			X	
Using standardized processes			X	
Having compact package	X			
Having resistant packaging				X
Good looking		X		
Reusing materials			X	
Having easy materials separation			X	

The importance degree must be acceced with the customers always as possible. When it is not possible the grades must be set collaborativelly.

The Fourth step involves generating the project requirements. They are based on the needs raised, making them measurable for the project (Table 5). It represents a difficult step as one must previously knows some phisical quantities.

Table 5. Step 4 Tool – Exerpt.

Needs	Requirements	Units	Instrument
Having few parts	Number of components	UN	Visual
Having low cost of production	Maximum cost	$	Costing method
Using standardized materials	Number of materials	UN	Visual
Using standardized processes	Number of processes	UN	Visual
Having compact package	Package size	mm	Measuring tape or others
Having resistant packaging	Package resistance	N/m	Mechanical test
...	...	...	...

As can be seen, each need must be converted on a measurable requirement. It can be checked if it has a unity and an a measument instrument can be defined.

The Step Five involves the valuation of the requirements through the tool House of Quality (QFD) in a simplified manner. The model presented by Rozenfeld et al. [4] can be used by restricting the fields only to the needs, requirements, customer value, degrees of relationship and the final score (Table 6).

Table 6. Step 5 Tool – Basic QFD – Excerpt.

Needs / Requirements	N. of components	Maximum cost	N. of materials	N. of processes	Packing size	Packing stiffness	Housing shape	...	**Weight**
Having few parts	5	1	3	3	5	6	5	...	**3**
Having low cost of production	5	5	5	5	3	3	1	...	**5**
Using standardized materials	3	1	5	1	1	1	1	...	**5**
Using standardized processes	1	3	3	5	1	3	3	...	**1**
Having compact package	3	3	1	5	5	5	5	...	**1**
Having easy materials separation	3	1	5	1	1	1	1	...	**1**
Being compact	1	3	3	9	1	3	3	...	**5**
...	...	...	...	...	...	...	...	...	**1**
Sum	156	240	350	80	50	70	250	...	
Ranking	**12**	**7**	**1**	**17**	**21**	**18**	**6**	**...**	

As can be seen, the customer needs are placed in the row, and the requirements on the columns. On the intersecton between the two a score is set (1, 3 or 5).

The sixth step involves drawing up the list of project-target specifications, organized in a ranking of importance derived from the QFD (Table 7).

Table 7. Step 6 Tool – Excerpt.

Ranking	Requirements	Units	Instrument	Specifications
1	Battery life	hours	Chronometer	200h
2	Materials strength	N/m	Mechanical test	1N/m
3	Average surface roughness	µm	Rugosimeter	1 µm
4	Maximum cost	$	Costing method	R$150
5	Maximum cost	$	Costing method	R$150
6	Housing shape	mm	Visual	5x7x3cm
7	Housing volume	cm^3	Measuring tape or others	$105cm^3$
8	Product strength	N/m	Mechanical test	1 N/m
9	Number of materials	UN	Visual	2 UM
10	Elasticband flexibility	mm	Measuring tape or others	300mm

This last table constitutes the end of the informational design and represents me main requirements in order of importance and its specific values to be chased in the next development stages.

4. Validation and Results

This proposal has been validated through a presentation to the product development team leader. The steps discussed here and the templates presented were organized on a Microsoft Power Point and presented on a meeting, with the other two designers. The steps to introduce the six simplified NPDP informational design steps were showed with instructions on how/what to do based on practical examples and the templates.

After finishing the presentation a discussion was conducted and a questionnaire was applied. The questionnaire was focused on the evaluation of the steps by the company and contained questions directed to the most difficult points in the application. It was also asked about the possibility of implementing the steps in the company, and if they applied any similar methodology/methods/tools for the early stage of the NPDP. The questionnaire consisted of six questions and is available at: https://pt.surveymonkey.com/s/JJBDXZN.

4.1. Results

The questionnaire showed that the steps had good acceptance by the product development manager and company owner. He claimed not to practice any kind of formal methodology to the NPDP early stages, and reported a strong belief on appling the proposed steps in the company's future projects. When questioned if he wanted to eliminate some of the proposed steps the answer was negative, the manager added saying that the steps were complementary and would not make sense if any of them was eliminated or implemented in a different order. Step number 5 was quoted on the difficulty of understanding and application, the house of quality step. The manager said he had taken longer to understand the tool.

The results can be seen as positive, but the manager emphasized his belief that in very young companies a frequent consultant monitoring would be required. About 18 months after the steps submission the pilot company was accessed again. It was found that the process had not yet been deployed. According to product manager it did not happened due to difficulties in fitting the training and procedures in the company's schedule. At the end what seems to emerge is the common resistance to changing that affects small and large companies and the virtual confort zone provided by informal processes.

5. Discussion, conclusions and recommendations

To better check the proposed steps it would require the practical application in several MSC NPDP projects. No quantitative or statistical analysis can be provided by this study, but the structure presented here can lead such studies. This could foster broader discussion on their efficiency and is aimed as a future research. The current results point that they proved qualitatively suitable for the pilot company at least. Despite they are not being implemented, one must consider the natural resistance from MSCs on formal processes. The apparent difficulty of NPDP methods must be considered and contoured in accordance with reality and the degree of development of the MSC. Thus, this work achieves its original objective. A simplified guide is presented for the informational design phase of the NPDP. However, the accompaniment of a product development or innovation agent is recommended, aiding in the understanding and application for the first time, or even more, NPDP projects. As the suggested steps focus on the early stages of the NPDP, it can be suggested as future work focusing on the later stages.

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Advances in Smart Manufacturing Change Management

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Abstract. Many manufacturers lack comprehensive and seamless management for the change processes occurring between planning and the shop floor – particularly when it comes to cross-location, cross-disciplinary, and cross-departmental planning. This paper describes the emergence of the PSI/VDA recommendation which addresses this challenge. It´s Manufacturing Change Management (MCM) defines a reference sequence of steps for managing the changes between planning and the shop floor. To define this reference process, the recommendation first discusses how MCM fits into the business environment and identifies the main participants of the change processes. Next, the best possible structural steps involved in the processing of a change enquiry are detailed and the typical tasks and their extents are described. Leading on from the conceptual basis of the MCM process, its suitability for specific applications within companies is then discussed in reference to relevant use cases. Next, the recommendation shows how to work out a software-based support structure for the concept and implement as a prototype. The key element of the software-based implementation is to map the changes within a superordinate change list. Lastly, the solution provides an easy-to-use practical tool for initiating change enquiries. This can be deployed flexibly on mobile devices such as tablet PCs on the shop floor.

Keywords. Digital Factory, Product Emergence Process, Production Planning Process, Reference Process, Manufacturing Change Management

Introduction

A dynamic business environment and the rapid changeover to a seller's market have gradually increased the complexity that companies are facing today. Change management within the product creation process has been turned into a vital success factor for globally active manufacturers [1]. The coordination and structural mapping of product changes known as 'Engineering Change Management' (ECM) covers only part of the change processes within the digital product creation [2][3][4]. The production systems for manufacturing and assembly of the products are likewise subject to many different changes [5]. Some of these changes are pre-planned, and they are implemented specifically to achieve efficiency increases [6]. Other changes are subject to processes that are less structured or planned, which means that their practical repercussions often cannot be adequately predicted. Typical for all of these types of change measures is the fact that the production system's applicable documentation and the actual state of production are inconsistent with each other – they are asynchronous.

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The applicable documentation for the creation, commissioning, and operation of production systems is provided by the planning documentation. At the commencement of production, the documents and definitions of the planning departments serve as a reference for everything. There are many different ways in which the planned state can be deviated from [7]. There may also be entirely different adjustments which cannot be visually mapped and evaluated as easily [8]. The triggers for changes can vary, and they may be identified and suggested by a wide variety of parties [9]. Starting with the implementation of the initial production process, the many changes that are introduced subsequently therefore represent the actual manufacturing process at any given time.

In the context of holistic production systems (HPS), the adaptability of manufacturing processes is crucial to competitiveness. Across-the-board efficiency increases are usually demanded on a yearly basis, creating a strong need for streamlining. In order to permanently adapt and optimize the process, the planning documentation will, sooner or later and indeed necessarily, deviate from the actual state of the production system. This means that all producers will experience their manufacturing processes deviating from the original planning state to some degree. Any changes to the manufacturing process and planning then take place over the course of an iterative process requiring the agreement of numerous participants [10][11].

Long-term production efficiency relies on a well-coordinated interplay between planning improvements and ongoing optimizations. Continuous and parallel process optimization means that every production and work plan is changed several times over [12]. The challenge today is that the departments involved in changing the processes cannot fall back on generally acknowledged methods, which leads to coordination problems further down the line. This results in delays in the documentation process – not to mention delays in adapting the plan and/or implementing it on the shop floor. There is a definite need for collaboration, particularly in order to [13][14][15][16]:

- optimize sustainable implementation of planned production processes,
- identify and minimize discrepancies between planning and the production process,
- improve synchronization between production planning and production, and
- provide IT support for management during the manufacturing change process.

In order to embrace these goals, the Digital Manufacturing project group, founded by ProSTEP iViP Association in 2010, has been working on Manufacturing Change Management (MCM) since 2013 [17]. The project group has begun to define implementation scenarios as typically experienced in the change processes [18][19]. The recommendation at hand describes the ideal procedure and detailed processes that have been proven to be meaningful and helpful for all involved companies [20]. With insights gained from user interviews on general practical needs, change processes are divided into individual, formalized sub-processes. These sub-processes form the basis of a recommendation for a MCM reference process. In addition, the recommendation describes the current state of processes within MCM, the role of various parties within these processes, and the problems that arise from the inadequate synchronization of processes and planning due to documents that are not updated as frequently as required . To achieve efficient management and coordination of changes within the production system, it is also necessary to implement technical software support; this is to provide for easy capturing and administration of changes as well as presenting them in suitable ways [21]. The remainder of this paper describes the emergence of the recommendation as well as the introduction in a prototypical implementation of the requirements.

1. Description of the MCM Process

However, as much as production planning cannot work without the input of many business units, so is it also impossible to say that the change process is subject to the influences of planning and production alone. Although not a complete list, the following is a look at some potential sources of input [22][23][24]:

- Production planning analyzes the market and customer requirements, leading to decisions on which product should be put into series when.
- To do so, it requires data and input from technology and innovations planning. The product and technology planning sets the prerequisites for final product development.
- Product development then provides both product data and the requirements for material, machine, and installation parameters (e.g., torque values).
- Quality planning requirements, in turn, influence the production systems to be deployed.
- Tool planning is a cornerstone for engineering the production system itself.
- The holistic production system provides a framework for determining strategic guidelines on production development.
- During preproduction and even after series production has begun, additional changes are recognized as being either necessary or expedient, and are implemented into the process. They are subject to the continuous improvement routine (Kaizen / CIP).
- The companies suggestion system also provides input by giving incentives to suggest operational improvements; this is particularly active as a source of input once production has begun.

The sheer amount of those involved is challenge enough, as the company must find a procedure that acknowledges relevant input and is accepted and used by all parties. There are in fact two important locations at which the production plan is stored: production planning, and the shop floor. The shop floor receives the plan in the form of work plans and work place documentation, but it is production that takes responsibility for the shop floor documentation. Changes to the production and installation documents, usually available to these departments only in paper form, are in the worst case documented by hand only.

As there often is no formal way to report to production planning, the plan and the actual production are no longer synchronous. As the changes take place dynamically and for a variety of reasons, a regular documentation schedule simply means locking in the asynchronicity between production planning and shop floor. The results of asynchronous documentation of manufacturing processes are so severe that the group participants view official information management between planning and production as an urgent requirement. In the recommendation, this information management is described as Manufacturing Change Management (MCM). This basically consists of two structural stages: the Manufacturing Change Request (MCR) and the Manufacturing Change Order (MCO).

To be implemented, however, MCM should not entail the creation of any new departments or units, but rather be integrated into the existing organizational structures for planning and production. Changes which may have considerable consequences for production require unambiguous documentation and assignment of responsibilities. In some areas, such as ideas management (company suggestion system), these approaches are being applied already. A guided change process for planning and production therefore relies on a predefined role concept that details the required tasks and responsibilities. In terms of the MCM stages, this suggests two employee roles for MCR and MCO operation respectively. The responsibilities of the MCR and MCO operators are derived from the requirements of day-to-day production, which in many cases are identical to the responsibilities of the organizational structure for planning.

While the causes behind manufacturing changes may vary, their inclusion in the MCM's change processes need to be uniform. Especially if a large number of employees and other parties are involved in production planning and manufacturing, it is important to be able to consistently map the change processes. Product changes necessitate additional assembly steps, new technologies alter the production flow, and employee suggestions help to optimize processes in production and logistics.

Within the scope of MCR, all of these manufacturing changes are captured and checked in terms of their permission to trigger a MCO. Within this first stage of the overall MCM process, both the initiators of the change enquiries as well as the employees who implement them are known; they are predefined as part of the company's in-house rules and modalities. Structurally, the MCR process can be subdivided into eight sub-process steps with varying levels of complexity. Steps one to five serve to fully capture the change enquiry, whereas steps six to eight initiate and implement the enquiry's evaluation in terms of downstream process flows within the overall MCM process. Within the given level of abstraction, these steps are context-independent and can thus be applied to any parties (any relevant MCM change enquiry).

Having uniform management and tracking of change requests provides a significant advantage, namely the reinforcement of standards within the improvement of standardized production systems. Approved changes to the production system can offer significant opportunities of improvement for other system areas – or even other departments or company sites – that are identical or similar. The last step of the MCR process is to prepare the change order. Essentially, this step comprises two implementation tasks. First, a suitable contact person needs to be chosen for implementing the change request. This person acts as the MCO operator and is responsible for all subsequent processing of the change request. After the MCO operator is assigned, the change order itself, the Manufacturing Change Order (MCO), is issued. MCO specifies the implementation of the requested manufacturing change.

2. Implementation of MCM in the Company Environment

Although a tightly structured and standardized MCM workflow is not yet facilitated in most companies, it is of paramount importance to analyze how change processes between planning and the shop floor are currently handled in companies. This involves identifying important methods and systems that are compatible with the MCM concept. As part of the Digital Manufacturing project group's activities, extensive interviews were held across the participating companies to find out more about this. A big part of the interviews was to capture and categorize the participants of the MCM process, the deployed or deployable methods, and the IT systems available for the implementation and documentation of the change processes. In order to create a clear picture of how change communication is currently being implemented, the interviews were followed by a concept phase of extracting commonalities from the company-specific constraints and integrating these into a neutral overall concept that will be outlined below.

The company-specific view of changes in planning and production has confirmed the initial hypothesis that there is a multitude of change triggers and initiators needing to be dealt with within a company's day-to-day operations. Next to product and technology advances, the main triggers for change are the continuous improvement process, expert projects, and a dual stream of strategic changes. As well as external triggers for change from customers or suppliers, there are also different internal groups of potential initiators which are spread across the product creation process.

As well as the different ways of initiating change, day-to-day company practices have also revealed a variety of methods and bodies for examining changes and decision-making processes. When it comes to work structuring, companies frequently rely on the expertise of their in-house HR and industrial engineering teams; more complex technological decisions are usually made by expert teams or dedicated core technology teams. In terms of the measures potentially resulting from a change project, the estimated project volumes are frequently a crucial factor in shaping the decision-making process. In addition to the project structure, there are many other implementation structures to be found in the area of MCM: from specific adjustments through to more extensive change measures, and through to large-scale projects such as technology changeovers or the redesign of entire manufacturing and assembly areas.

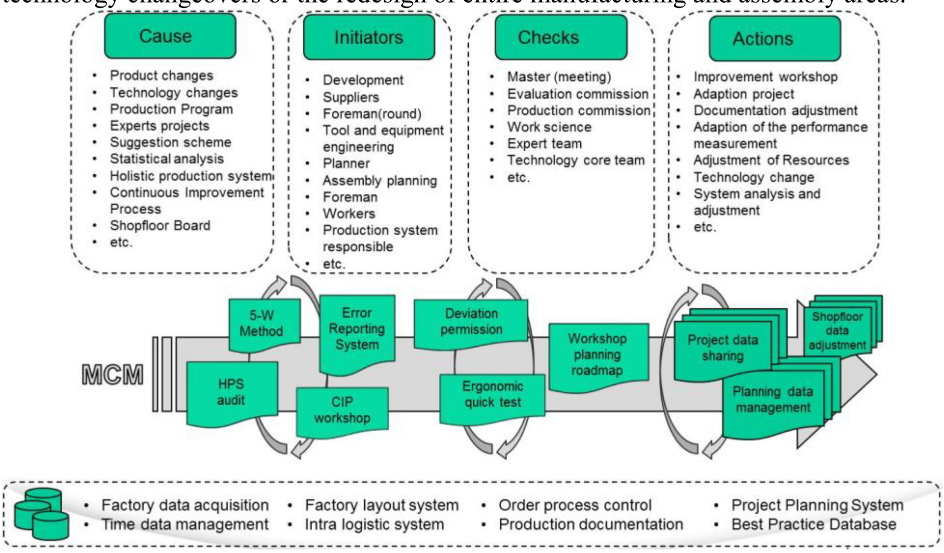

Figure 1. Change communications in manufacturing companies

In order to make their heterogeneous MCM environments more manageable, the analyzed companies are deploying many different methods and tools for a variety of practical purposes. Many of these methods are designed to identify divergences between the actual system and its current documentation. They aim to find out how these arose and also to trigger the synchronization of the actual system and its documentation. Companies are striving for an efficient combination of flexibility and stability in the interplay of documentation and shop floor. This enables methods such as deviation permissions or quick ergonomics tests to examine and evaluate actual states without significant administrative involvement. The described methods are complemented by a wide range of mechanisms for consistently and uniformly managing the planning data being created. These include workshop planning roadmaps, planning data management, project data sharing, and shop floor data adjustment.

Product development is one of the main triggers of change processes in planning and production. The product requirements implemented here – triggered either in-house through quality management etc. or externally through customer change requests – result in a change process that is established very rigidly in most large-scale manufacturing companies. Engineering Change Management (ECM) is a widely-used standardized approach for implementing change processes pertaining to product data as well as the controlled adjustment, approval, and deployment of the changed information. The changes arising from ECM when a new product or derivative is introduced, or when existing products are changed, additionally require validation in the downstream planning and production areas.

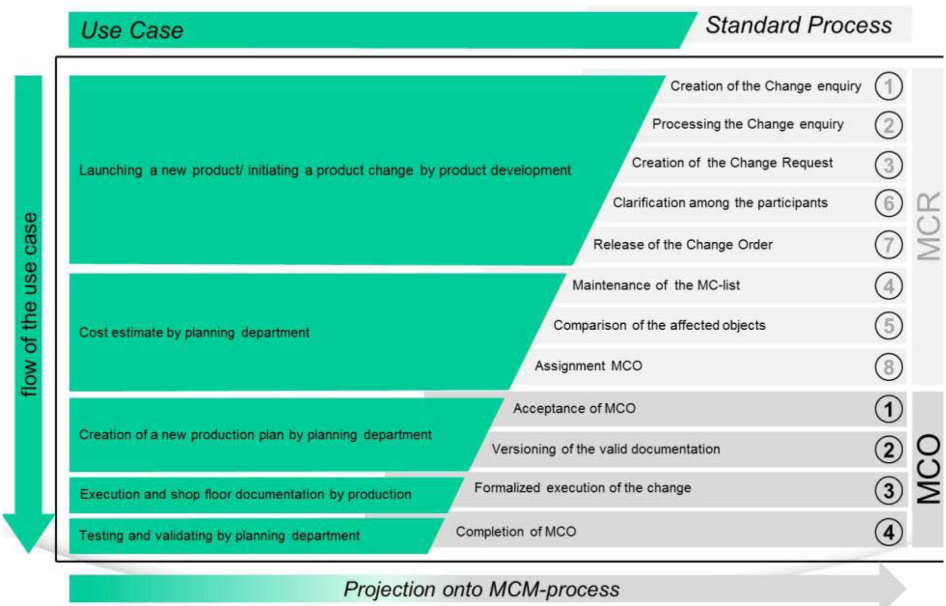

Figure 2. Mapping the 'Engineering Change Management' use case to the MCM process

Here, the changed structures in product development are made accessible to the planning department. If the changes apply to individual parts, the updated drawings and any available updated descriptions are also transferred. In this context, the main task for the planning team is to identify and capture the production system objects being affected by the change, and to estimate the costs of adapting the system to the changed product characteristics. After that, the planning team puts together a new or revised production plan and updates the shop floor documentation to reflect any changed details of the process implementation. In the event that the system adjustments require investment into new production equipment, machines, or systems, the planning department is also responsible for acquiring these alongside any needed raw materials, which may take the shape of a first batch. The changes are transferred to the production team in the shape of a work plan alongside detailed.

In the next step, this same documentation is used for physically implementing the changes on the shop floor. The production team is responsible for implementing the changes to the physical system in a way that conforms to the documentation. Following the adjustment process, the changes implemented within the actual system and within the documentation are validated and confirmed by the planning department.

One of the main drivers for change to the physical manufacturing system is the continuous improvement process (CIP), which is a well-established concept in many companies. The objective of the CIP is to gradually adapt and adjust a production system in order to increase its performance. For the purpose of implementing major changes to production systems that go beyond adjustments during regular operations, many manufacturing companies run so-called CIP workshops where the implementation of efficiency-boosting measures can be discussed in-depth. A CIP workshop typically focuses on the improvement measures of just a single area of the production system; this makes it one of the prime drivers of change processes pertaining to production and the associated planning areas.

Looking at the use cases overall, it is evident that while they may vary in the way they relate to the structural MCM process within operational practice, they can nevertheless be mapped to it very consistently. What has also become evident is that in practice, multiple steps of the standardized MCM process can be grouped together within a single process step, which makes them more manageable. The possibility of mapping the standardized MCM process to use cases therefore provides a feasible basis for a streamlined, software-based implementation; however, due to the individual functions being integrated very differently, the implementation cannot at this stage follow a fixed technical workflow.

3. MCM Prototype

A key factor in implementing the Manufacturing Change Management concept is to implement the process in a way that causes the participants as little added effort and cost as possible. This is particularly relevant to the ‘CIP’ and ‘Undocumented changes’ use cases, as there is very little willingness for these to take up additional effort and cost for documentation. What’s needed to make MCM implementation possible is a highly flexible IT support structure that facilitates the use cases to be implemented in practice. In the production environment, a large portion of the input is to be entered automatically, such as the user name or the production line in question. To provide a rough idea of what kind of shape the required IT support might take, the Digital Manufacturing project group within ProSTEP iViP has developed the so-called MCM Prototype; this is a prototypical implementation that demonstrates the kind of IT support needed for the MCM process. As the prototype was developed with a German user interface, translations for the relevant elements used in the screenshots are given in parenthesis where necessary. The demands placed on the MCM Prototype are informed by the task to manage the manufacturing changes as efficiently as possible. For this, individual change objects need to be both creatable in the context of linked structures as well as manageable in the context of other changes (Figure 3). The central element of the MCM data model is the MChange object. This represents an individual manufacturing change. The MChange object is created and persistently stored within the first step of the MCM process – the creation of the change enquiry.

Throughout the MCM process, the MChange object is populated with attributes and links to other objects. Besides the unique ID, the status is the object’s most important attribute, as this is used to map the progress of processing the manufacturing change within the MCM sequence of steps. The status can also be used as the key characteristic of a workflow engine controlling the MCM process. The MCM Prototype at hand does not feature a workflow engine because support for the MCM process needs to remain flexible; the aim here is not to prescribe fixed processing methods but to support responsible parties in the management of change processes. Also, most companies already have their own workflow systems – the prototype at hand is designed to be integrated into these rather than adding yet another workflow engine. Further attributes of the MChange object include type, scope, responsible party, and planning periods. 'Type' indicates the type of the manufacturing change. In the MCM Prototype at hand, the values stored here include 'ECM' for engineering change management and 'CIP' for continuous improvement process. 'Scope' contains a more detailed description of the planned or ordered change. The 'responsible party' attribute indicates the person responsible for the change, which usually is the assigned MCR or MCO operator. At the point of creating the change, the 'valid to...from' period may not yet be defined, so the entries here are optional and can be estimated. Over the course of the MCM process, this attribute will therefore need to be updated and locked down, as it is needed for defining the time axis when mapping a series of planned changes.

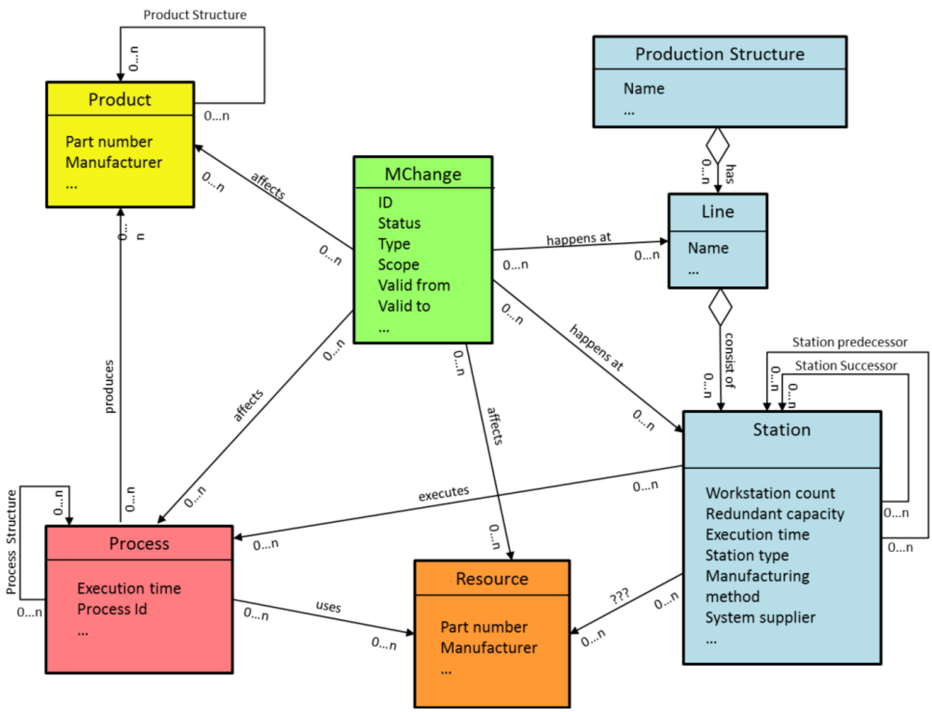

Figure 3. Data model of the MCM Prototype

The most important aspect of the data model introduced in Figure 3 is that the central MChange element is linked to the objects of the digital factory, i.e., the process, the product, and the resource. The resource is particularly important in this context and its use is expanded. By distinguishing between resources such as machines and tools – as well as between manufacturing structures such as lines and stations – it is possible to consolidate resource uses and see how resources are linked to manufacturing changes. For example, all of the MChange objects linked to a particular station can be determined this way. Similarly, this process can be consolidated to determine and display all of the stations of a line, as well as the MChange objects linked to the line itself. Single resources such as tools can be allocated to multiple stations and conversely multiple tools to a single station, and again they can also be linked to the

MChange object directly. The product and process structures are mapped in the same way, permitting context-specific views of planned manufacturing changes currently being implemented, as well as future planned manufacturing changes. For each product and each component contained within the product structure, the allocated MChange objects can be viewed. The same applies for the processes and process structures. In addition, the products, processes, and stations are linked together. This makes it possible to determine the processes allocated to a product, as well as the stations allocated to the processes where these are being implemented.

The network structure of the data model centered on the MChange object forms the basis of the MCM Prototype. The MCM Prototype is a web-based application with a client-server architecture. The interface is provided in the form of a web page, which can be opened via a standard browser from any user device that has access to the MCM web server.

The MCM concept is currently being tested in pilot projects by the manufacturing companies participating in the Digital Manufacturing project group. The testing involves users from many different areas including production planning, industrial engineering, and manufacturing. To support the pilot projects with supplementary measures, the project group has compiled a number of different work packages. On-site workshops are being offered to teach users about the overall system structure of the Manufacturing Change Management. Because the pilot projects are being carried out using the MCM Prototype, additional installation and configuration support for this is also on offer, as is a training module on how the MCM Prototype is used. Over the course of each project, a dedicated user support team is recording any issues that are arising, as well as the experiences gathered during the pilot project. Upon conclusion of the pilot projects, the participating companies will validate and assess the MCM implementations.

On the vendor side, a range of different PDM and PLM systems are being analyzed for their suitability to support or even integrate the MCM concept. Based on the experiences collected from the pilot projects and the analyses of the vendor systems, an MCM Implementation Guideline will be compiled to aid companies in implementing the MCM collaboration concept within their planning and production environments.

4. Summary and Outlook

With its Manufacturing Change Management, the Digital Manufacturing project group from ProSTEP iViP has created an informational collaboration concept to address the dynamic manufacturing changes taking place between engineering, production planning, manufacturing, the production system, and ideas management [25].

The formalized MCM process facilitates the creation and management of manufacturing changes across a company’s different departments; due to their diverging priorities and the possibility of overlapping implementation schedules, manufacturing changes have the potential to interfere with each other. To prevent this from happening, the MCM process facilitates the systematic processing of these changes in the context of existing production structures, manufacturing and assembly processes, resources, and other planned changes [26]. A prototypical software implementation, the MCM Prototype, provides the necessary IT support for implementing the MCM process in practice.

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Implementing a Strategic Alignment and Approval Model for Projects in the Selection and Development of New Products in the Brazilian Telecommunications Segment

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Abstract. Considering the need for approval and implementation of projects that enable the strategy of organizations, this paper presents the results of the implementation of a process for project´s selection with technological bias and the need for financial investment in a multinational company in the telecommunications industry. During this study the stages of approval flow are presented, starting with the composition of the macro scope and expected benefits, following by the determination of the needs of investment and financial analysis and concluding with a discussion of their representativeness across the company strategy and approval itself within an executive committee. In addition to the presentation of the model, this article discusses the practical results and improvement needs after elapsed its early stages of implementation. This paper is concerned including in determining the limitations of this model and cultural factors involved in its implementation on a large organization.

Keywords. Product development; project management; project selection methods; strategy

Introduction

The search for excellence in the development of new products in the Brazilian market has taken a new direction. For many years, the economic development realized by the principle world economies (Brazil being one of them) placed the efficiency of the development process as the main focus. The quality of new products and the speed with which these products were placed on the market has always been an important relevant factor, principally in segments where competitive advantage is a deciding factor in launching a product. Understanding the context for the development of a new product from the beginning (the idea) to the end (product launch) is essential to its success [1].

However, even considering the necessity for speed in the launch of new products, the process between the brainstorming and the transformation of idea into a successful product on the market has been very restrictive [2].

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Choosing the right strategy for portfolio management and the right balance between innovation and extending existing product families become critical decisions when dealing with the costs and speed of implementation [3]. Where corporate resources are allocated as a result of executive agreement is a crucial factor in achieving relevant results for the business [4].

In the face of an economic recession in the Brazilian market in 2015 and 2016, another criterion of utmost importance to be taken into account in the development of new products is how effective the process is. In other words, what percentage of the products created by the company become successful commercial initiatives. In this scenario, what matters is not necessarily how efficient the process is, but how effective it is. When financial resources and market demands are presented as restrictions, the development process of a company is able to demonstrate sensitivity to these factors.

Considering that the competitiveness of a company depends on the combination of lucrative and successful projects [5], it makes sense to consider strategic alignment in the selection process to ensure that projects are implemented as efficiently as possible. In this case, efficiency and effectiveness in the project development process become equally important.

In an unfavorable macroeconomic scenario, it is not enough to drive development of new products independently from the organizations' strategy seeing as an efficient selection process for new products directly impacts the company's productivity and profitability [6]. Even today, the majority of project management techniques focus on the execution of actions [7] and not on a strategic understanding of the reasons which led to its approval by the executive board.

The definition of an organizational strategy, the establishment of a clear selection process for projects, the consolidation of the way company strategy is being fulfilled in the delivery of that product, the ability of staff to see this strategy in a playful and clear manner throughout the entire product development life cycle, and the establishment of efficient, multi-dimensional development which reduces the need for rework and meets the needs of the stakeholders are all themes that this article intends to address, bringing to light opportunities to develop work that can increase productivity and profitability while reducing the uncertainty of the product development process in different types of organizations.

1. Theoretical Framework

The subjects of New Product Development Management and Project Management have been constantly mentioned in similar contexts in recent years. Issues such as Concurrent Engineering and Product Lifecycle Management point to the need to carefully consider each stage of a product development project. Competition for resources, parallel activities, rework, and the reduction of the development cycle aimed at an anticipated release are common issues that are worth analyzing from another perspective.

Consistent new product development processes have already been outlined by various authors connected to the engineering segment, of which successful models have been described by [8], [9] and [10]. In the midst of economic growth, the creation of models that feature strong technical content and little connection to organizational strategy are viable [11]. However, this is not the current state of the Brazilian market.

Another factor to consider in a model is the participation of stakeholders in the process and the reduction of uncertainty related to public results, insofar as negative influence may arise during or even after a project launch [12]. The possibility for learning and logging all the stages of the process is also a critical factor for effective management [13].

Considering that there are many stakeholders within a product development project and that they act in different capacities within the executive organization, concurrent engineering came to fill a space where product development should be seen as a systematic approach that considers multiple pertinent aspects of a project simultaneously with the product lifecycle, project management, and the development of processes and all stages related to it [14].

Source [15] understands concurrent engineering as a product development methodology due to not only its aspects related to integrated development but also its concern for relevant issues that help the success of a launch, such as concern with time compression.

In comparison with product development sequential models, it is clear that concurrent engineering has an immediate concern with reducing the time for launching a product into the market.

The creation of great concepts, and consequently successful products, should be associated with the market launch using a systematic and disciplined approach from idea to product release [1]. The process used to conduct the flow of the development of a product is known as Stage Gate. According to source [16], the Stage Gate model is a conceptual and operational process that guides the development of new products from their initial idea stage to their launch and even beyond (during their post-production stage). Stage Gate maps out what needs to be done, how it should be done, and in what order.

Stage Gate consists of a series of stages where work on the project is done, information is obtained, and analyses are completed as well as all necessary integrations following the Gates series of stages). During these stages, GO/NO GO decisions are made which direct whether or not to continue investing in the project [16].

Understanding the product development process goes beyond technical and engineering steps; it has consolidated over the years, and with some authors such as [17], evolved to incorporate other steps involved including a vision of marketing and the end consumer at the beginning of the process as well as a post-launch analysis, not only to analyze the results, but also to learn from them. Rozenfeld’s model is structured in three distinct phases: pre-development, development, and post-development, wherein a series of developmental stages exist [17].

The first phase prioritizes the concept of the strategic planning of the product, while the latter is concerned with a more integrated view of the product lifecycle, including its discontinuation.

2. Methodological Procedures

This research aims to outline a proposed new consistent work model for product development within medium to large organizations. Due to the need for consistency in this type of work and the fact that it requires a certain level of detail and proof of the success of the proposal, it was decided that the case study be carried out in a large telecommunications company.

Although it is not possible to draw generalizations through one case study, it does allow for in-depth research into the topic and is fundamental for the establishment of a working proposal.

The focus of this study will be a large company in the telecommunications and cable TV segment. This company began selling plans for fixed phone lines over 15 years ago, later adding to its portfolio high-speed internet access products and telecommunications services for large businesses. It launched subscription TV service in 2011 as well as value added services such as anti-virus, online backup, etc.

In addition to being able to conduct a thorough observation of the product development process, this project allowed for the implementation of the proposal in a systematic way and for the assessment of the impact on consumers and internal project team members in a real world environment. All of the results could be measured and presented in order to get a complete understanding of the proposed method and its impact on a large organization in an extremely competitive field.

According to source [18], the choice to conduct a case study is dependent upon the question being researched, and the more that question seeks to explain some present circumstances, the more relevant it becomes. In this case, apart from the search for an explanation for the phenomenal success of the development of products in organizations, this research study seeks to change pre-established models and to create a strategic alignment process to maximize results.

3. Problem Formulation

According to a major benchmark study on project management in Brazil [19], 50% of organizations still highly resist the execution of project management techniques and methodologies and 48% demonstrate a low level of support for the top management of an organization. In other words, there is a significant need for progress in convincing these organizations that project management practices can have positive results in new product launches.

Another relevant point that underlines the necessity for more effort in the search for efficiency in product development is that 26% of Brazilian companies do not provide enough time for the planning stage.

This benchmark study also looked at the importance that is given to aligning projects with the organization’s overall strategy. It became clear that respondents believed that there is a relationship between the alignment of strategy with the success of developed products, but again, it exposed problems with that alignment. The 2013 study found that 56% of organizations execute projects without previously aligning them to their strategy, and 40% of organizations do not have a structured selection and prioritization process for projects.

Another issue that warrants further research into strategy alignment models versus product development processes is the fact that only 17% of companies have a consistent process for measuring and monitoring the results of their launched projects.

Even with a well-defined strategy and a consistent project selection model (two topics that will be addressed in this article), the efficient development of projects using tested methodologies is fundamental to the achievement of expected results. However, today most organizations do not have this as only 43% of companies surveyed have a single methodology for project management.

According to [20], companies with a low level of maturity in new product development processes do not have clearly defined product objectives right at the beginning of the project.

Thus, the question to be addressed is how to combine an organization's strategy with the implementation of new products by using a consistent selection and prioritization model and to take apart the outcome of this selection in an efficient process of developing new products without losing strategic insight [21].

Considering that factors relating to management processes of product development and methods of selecting projects are directly related to commercial launch success [22] and understanding that the steps related to the process aimed at defining scope, financial analysis, product development in all areas of the business, and commercial launch are subject to failures related to lack of staff motivation, strategic alignment, and scope changes in later developmental stages points to the need for a model that minimizes these problems. The objective of this article is to present such a model.

4. Proposed Solution

It makes no sense to minimize the effects that compliance to the launch of a new product has on an organization's strategy. Even when the development seems to have had its origin in a good idea, there are mechanisms within a company that enable the success or failure of a product and to ignore these influential forces maximizes the probability that the initiative in development will fail.

As the question of strategic alignment is a crucial one, the first task of those responsible for the selection of new projects is to clearly understand the pillars which sustain an organization's strategy and create a visual model for these pillars, summarized in order to provide quick reference when analyzing a new project.

In this case study, the organization held a strategy called "Intelligent Growth", with three pillars (premium positioning, investments with better returns, and operational efficiency) that were used to direct the approval of new products.

The establishment of strategic pillars becomes essential to associate how a project is adhering to these pillars. In the case discussed in this article, an index known as IAE (Index of Adherence to Strategy) was created to be responsible for this relationship in the new project selection flow. The adequate selection and prioritization for projects is very important for organizations [23], being that this selection is nowadays frequently used as a method to decide on the authorization for the use of resources.

One of the ways to create and sustain a competitive advantage within companies is to be able to maximize the exploitation of their knowledge and skills efficiently and, of course, seek ways to innovate and flexibly respond to challenges [24].

This index created by the authors (IAE) can take on values between 1 and 5, being that projects scoring 5 show themselves to be completely aligned with the three organizational strategy pillars (or rather, excellent projects with a great chance of becoming successful) and conversely, projects with IAE values of 1 are considered projects unaligned with organizational strategy. In this case, they should not be executed.

Another relevant point was the creation of an IAE specifically for projects considered obligatory but that did not necessarily follow organizational strategy, such as adherence to regulations, new environmental standards, etc. (Figure 1).

Figure1. Index of Adherence to Strategy.

Defining the IAE becomes a central role in the new model of selection and approval of new projects comprised of five stages (concept and creation of a project, technical viability analysis, financial estimate and defining indicators, and strategic alignment and prioritization of project in committee). Figure 2.

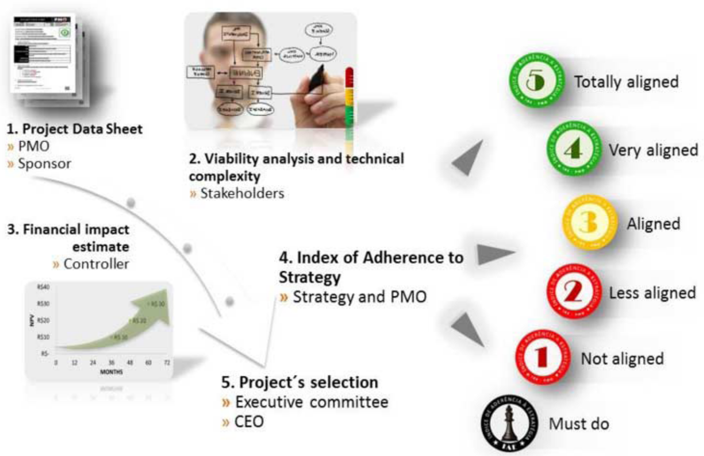

Figure 2. Project selection model.

During the initial stage, the product is conceived and, in addition to the scope and technical requirement items being established, a clear definition of the qualitative and quantitative benefits is produced so that the product may pass to the subsequent model stages. The second stage is realized after a clear understanding of the scope of the project is reached, and at this time, the internal and external suppliers technically analyze the issue and propose solutions to make the scope viable. In many cases, the scope must be adjusted due to infeasibility, and the expected benefits may possibly be modified as a result.

In the third step of the process, with the benefits and costs well-defined, the financial department of an organization works to define the financial indicators that define how attractive the project is. A number of indicators are developed. It is important to highlight that in cases where financial criteria are relevant, the return on investment (ROI) is an important deciding factor [25].

In the fourth stage of the model, the IAE (the Index of Adherence to Strategy) is applied, being that this index should respect the values between 1 and 5 and be directly associated with the strategic defined pillars of the organization.

The last stage in the process happens during a committee with the presence of key executives of the organization where each project is presented and defended by its respective sponsor, and approval is realized. As this approval is done at the highest levels of the organization, the project gains focus and attention in all areas. This point is fundamental to the success of this type of project because of the multifunctional character of new product development.

5. Results

This model was applied in the years 2014 and 2015 in a large telecommunications company, considering the product portfolio previously described in this paper and also the scale of operation throughout Brazil.

Considering first an overview of the results, this model allowed for a careful analysis of both quantitative aspects (especially financial) and qualitative ones (strategy adherence, positive experience of the end user, among others) never before analyzed by the company from a portfolio standpoint. In this case, as signaled by [26], there were gains in project management allowing for efficiency in the decision-making process.

Where previously financial analysis was performed but segmented only for a project already in development, now all projects are seen from a results perspective for the organization, especially in the fact that monitoring promised versus actual results is possible.

Table 1 presents the principal points identified after two years of study of this model within the aforementioned organization via stakeholder´s interviews.

Table 1. Impact analysis of the new model in the case study company.

Model Stage	Description of context identified in the company being studied
Project's conception and creation	1 - Significant cultural impact generated by the model, causing strong resistance both at executive and managerial levels.
	2 - Delay in the first step of the process because of a wrongfully assumed maturity in the process; such false assumption was perceived when the analysis included a wider range of departments.
	3 - The model made a comprehensible analysis of the scope possible before the beginning of the project, involving several departments within the company (complex projects listed over 30 different departments).
	4 - Several projects bound to fail were cancelled during the first stages of the process (reduced costs), for the analysis of quantitative benefits was mandatory.
	5 - Identification of the benefits during the first stages made the crossing of budget information possible, and budget adjustments were made when necessary.
	6 - All departments began to perceive all of their projects due to the need of handing in a detailed report, at the early stages, to the team responsible for choosing projects.

Model Stage	Description of context identified in the company being studied
Analysis of Technical Viability	1 - When involving external suppliers was needed, the analysis took longer than 30 days (beyond sponsor's expectations). 2 - Human resource expenses before the project's approval were seen as negative by the executives in charge, which caused resistance against the liberation of funds. 3 - Scope changes that impacted benefits were made often after technical viability analysis (item deemed positive once the adjustments were made beforehand). 4 - Excessive costs for the organization would put the project on hold until further chance of getting an alternate solution, avoiding waste of funds if the project were not viable. 5 - The thorough analysis by different internal suppliers (Engineering, Logistics, IT, Call Center) allowed for a higher visibility of the project's costs.
Financial Estimate and Definition of Indicators	1 - The analysis of financial factors made possible the adjustment of specific goals, and revealed the need for goal revision, which made them more aggressive. 2 - This stage allowed the company's controllership a more emphatic questioning of the project's results, causing conflict with the customer department and even with the sponsors themselves. 3 - The need to calculate financial factors prevents a more accurate estimate, which increases the duration of the analysis in order to allow the calculation of a more accurate cost. 4 - Many times the first two stages of the process lasted longer than expected, which pressured the financial department to finish the third stage quickly. 5 - The existence of detailed financial factors, made by an independent department, made the decision-making process more realistic and with a bigger chance of success.
Strategic Alignment	1 - Transforming the strategy in easy-to-see pillars makes the perception of alignment easier. 2 - The strategy's stability is paramount in this type of model, once the strategical changes determined by the executive body demand adjustment by the IAE. 3 - Many times there's an expectation gap between the IAE expected by the sponsor and the IAE received after the analysis by the company's strategy department. 4 - The alignment with the company's strategic pillars allowed the CEO to perceive increased control over the process, making possible the release of funds for development. 5 - The composition of clear factors for the strategic alignment became essential for the conception and consolidation of the model.
Prioritizing the Project in a Committee	1 - Many times, the sponsor presents his project too fast to the committee, which generates doubt among the other executives and uncertainty in approval. 2 - Sometimes, several projects are defended in the same committee, which causes a drawn-out meeting and damages the projects presented at the end of the meeting. 3 - The meeting of an approval committee with the attendance of all executives enables the entire organization to understand and prioritize the project. 4 - The committee makes possible a broader discussion of the project, where departments such as Legal, Regulatory Matters, and others participate in equal terms with departments such as Marketing, Sales and others 5 - The committee allows even the mandatory projects to be discussed, and the risk of not executing them to be discussed by the executives.

A crucial factor for this model is the establishment of a direct relationship between the benefits and the selection of innovative projects that generate useful deliverables for the organization as it is through these results (strategically aligned) benefits for the company originate [27].

6. Model Limitations and Discussion of Applied Proposal

This model proved to have great use for the organization being studied and created the realization that strategic alignment allowed that the IAE be utilized even during the product development stages, after project approval.

The cultural question was an important factor in the initial implementation stages of the model and the alignment of the model at an executive level was fundamental to its maintenance. Monthly, all approved projects and their respective indicators are presented to the company CEO and validated by him. Projects not validated by him cannot begin authorized development.

A limiting factor considered relevant was the lack of a correlation between financial investments and pre-approved budgets. This association in the moment of implementing the model caused problems, as the search for resources within these areas created restrictions to project initiation, while the budget correlation caused a need for long-term predictability as to which projects go through the approval cycle--which would not be feasible in terms of organizational planning at this point.

The IAE (better known within the company as the strategic “seal”) began to be widely used within the company by sponsors to highlight the importance of a project, and this fact caused a gain for the team responsible for new project approval.

The meeting of the project approval executive committee always had a monthly basis, allowing that departments be assured that only mature projects were brought to committee approval. Knowing that there would be another committee in the following month, the department always opts for the most mature project possible to avoid rejection.

7. Conclusions

The possibility of creating a selection and approval model for new projects for large organization only became a reality due to the clear necessity for executives to have visibility of the current product portfolio and especially of whether the planned deliveries would deliver the strategy and expected results to the organization.

The benefits analysis in the initial stage and the involvement of the financial department in the project approval flow was a paradigm shift within the organization, seeing as analyses were often done in a partial manner, benefiting the concept-creating department, and the lack of or complete absence of financial understanding led to hasty decision making.

Portfolio management also presented gains as now all projects are seen through the same perspective and considered with the same financial indicators and strategic bias; company vision is consolidated and the organization knows which are their main projects and if their strategy will be fulfilled through them or not.

Finally, the cultural paradigm shift was relevant seeing as the model encountered much resistance in the first months of implementation for the given reason that it would add time to the product development cycle. This assertion with the passing of time proved misguided given that many projects that passed through the flow had a lower volume of changes, greater engagement and adherence to promised benefits. Later analyses showed that projects frequently delivered promised benefits during the conception stages.

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Identification of the Main Factors That Influence the Innovation Management Performance

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Abstract. To maintain a long term sustainable innovation program is fundamental to the organizations analyze the organizational and process factors that influence the innovation management performance. This analysis enables the enterprises to develop sustainable models and keep the innovation process in a continuous way. In this sense the objective of this paper is to identify the main factors that influence the innovation management performance and compare them with the innovation experts' view. In a first step an exploratory literature analysis was performed, resulting in a framework that describes the main factors of the product innovation management performance. In a second phase deep interviews based on the constructs described in the framework were carried on with five innovation experts. Final results of this research are presented in a second framework comparing the main constructs with experts' view.

Keywords. Innovation, innovation management, front end, performance.

Introduction

To evaluate the innovation management (IM) performance of an organization is necessary to measure its final results. But it's not enough, as final results represent the products that are already in the market without checking the sustainability of long-term process. To better understand this situation, Freitas Filho et al. [1] performed an exploratory analysis about the factors that must be taken into account when analyzing the IM performance. The authors presented a descriptive framework of the main factors that influence the IM performance based on the most cited papers from Scopus and Web of Science bases, considering organizational and process factors, as shown in Figure 1.

The framework is divided into four major dimensions. The first one is related to organizational factors, representing strategy, culture, leadership, organizational structure, resources and knowledge management (KM). The other dimensions are related to the stages of the innovation process, as defined by Koen at al. [2]. According to the authors, the innovation process is divided into: a) Front End of Innovation (FEI),

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b) Development of New Products and Processes (DNPP) and c) Commercialization. In relation to FEI the factors identified are the conceptualization, technology acquisition, market information and systems and tools. For DNPP the factors identified were product portfolio and project management and for commercialization it was not identified any new factor.

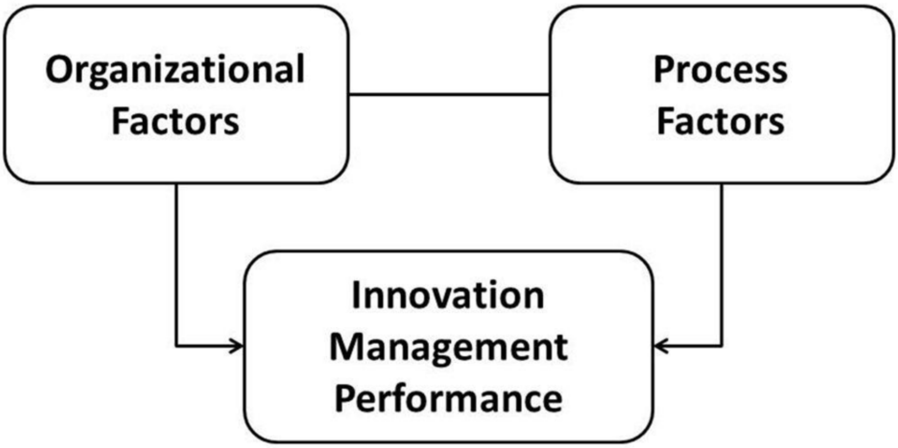

Figure 1. Relationship between organizational and proces factors with IM performance.

In this sense, the objetive of this research is to identify the main factors that influence the innovation management performance and compare them with the innovation experts' view. This comparison was made through in-depth interviews with five IM experts following a script based on the framework of the main factors that influence the IM performance. The respondents were people with large knowledge and experience in IM, who used to work with IM in multinational companies recognized due to high performance in innovation.

1. Theoretical reference

As a reference, the framework of the main factors that influence the IM performance was considered. This framework presents the main characteristics of each influencing factors and is shown in Table 1.

Table 1. Factors that influence IM performance.

Factor	Characteristics	Authors
Innovation Strategy	Long term innovation strategic plan; clear innovation goals; projects prioritization based on innovation strategy; innovation strategy flexibility to support environmental, market and technology changes.	Adams; Bessant; Phelps [3]; Francis; Bessant [4]; Cornican; Sullivan [5]; Bessant et al. [6].

Factor	Characteristics	Authors
Culture	Intrapreneurship; colaborative culture; constant change; innovation team autonomy; decentralized decision making; risk acceptance; open mind; innovation culture dissseminated to the whole organization; recognition and reward policy.	Chiesa; Coughlan; Voss [7]; Adams; Bessant; Phelps [3]; Hidalgo; Albors [8]; Subramanian; Nilakanta [9]; Cornican; Sullivan [5]; Bessant et al. [6].
Leadership	Senior leadership responsible for innovation results; leadership commitment with innovation and risk taking; shared decision making process; innovation goals shared by leadership; chalenged innovation goals; people management.	Chiesa; Coughlan; Voss [7]; Adams; Bessant; Phelps [3]; Hidalgo; Albors [8]; Prajogo; Ahmed [10]; Cornican; Sullivan [5].
Organizational Structure	Projects developed by multifunctional teams; involvement of the whole organization in innovation projects; innovation is considered as impact factor to the career process.	Chiesa; Coughlan; Voss [7]; Adams; Bessant; Phelps [3]; Cornican; Sullivan [5].
Knowledge Management	Knowledge sharing is stimulated; innovation portfolio aligned with organizational competencies; communication between Marketing and Research and Development (R&D); quick learning; knowledge repository; effective communication inside and outside project teams.	Adams; Bessant; Phelps [3]; Hidalgo; Albors [8]; Subramanian; Nilakanta [9]; Prajogo; Ahmed [10]; Bessant et al. [6].
Resources	Adequated infrastructure, human and finantial resources foreseen to innovation projects.	Chiesa; Coughlan; Voss [7]; Adams; Bessant; Phelps [3].
Conceptualization	Effective innovation process implemented; formal idea generation process; prioritization process based on innovation strategy; innovation concept portfolio; innovation projects aligned to innovation goals; alignment between consumer needs and technology; monitoring of new regulamentations and political rules changes.	Chiesa; Coughlan; Voss [7]; Hidalgo; Albors [8]; Prajogo; Ahmed [10]; Cornican; Sullivan [5]; Bessant et al. [6].
Technology Acquisition	Technology understanding and monitoring; technology strategy to support market needs; technology road map; adequated technical and R&D competencies.	Chiesa; Coughlan; Voss [7]; Tidd [11]; Prajogo; Ahmed [10].
Market Information	Consumer needs considered in innovation projects. Market needs and consumer behavior monitoring.	Adams; Bessant; Phelps [3]; Tidd [11].
Systems and Tools	Adequated systems and tools to innovation process; risk management; optimization tools.	Chiesa; Coughlan; Voss [7]; Adams; Bessant; Phelps [3]; Bessant et al. [6].
Product Portfolio	Innovation projects linked to product portfolio. Efficacy.	Alegre; Lapiedra; Chiva [12].
Project Management	Adequated product project management. Efficiency.	Adams; Bessant; Phelps [3]; Hidalgo; Albors [8]; Alegre; Lapiedra; Chiva [12]; Bessant et al. [6].

Factor	Characteristics	Authors
Commercialization	Consumer satisfaction research; market innovation monitoring; new products test; marketing campaigns and sales; new business development; competitive advantage.	Adams; Bessant; Phelps [3]; Hidalgo; Albors [8]; Mikkola [13].

2. Methods

This work is a qualitative research based on in-depth interviews with five IM experts. A semi-structured script based on the framework from Table 1 was used to perform the interviews. The questions used during the interviews are the following:

1. In general matter, which is the main factor that influences IM performance?
2. Talk about the influence of the strategy into the IM performance.
3. Talk about the influence of the culture into the IM performance.
4. What can be considered as a proper ambient to innovate?
5. How is the innovation culture disseminated in the organizations where you have worked?
6. How are people who innovate recognized and rewarded?
7. What is the role of leadership in IM performance?
8. How can the organizational structure impact IM performance?
9. How can knowledge management impact IM performance?
10. How do people share the knowledge inside the organization?
11. How can the internal relationship impact IM performance?
12. How can the resources impact IM performance?
13. How should the IM process be in an organization?
14. How can an organization create ideas and identify innovation opportunities?
15. Which are the main information sources to innovation projects definition?
16. What is the knowledge importance in IM performance?
17. What is the knowledge importance in IM performance considering market needs and consumer behaviour ?
18. What is the role os systems and tools in IM performance?
19. How should be the product portfolio regarding innovation projects?
20. What is the project management importance in IM performance?
21. How should be the follow up of innovation products after launch?
22. What can be expected from an innovation product in the market?

Thematic analysis was carried on in order to describe the main points cited by the experts. The analysis was presented in a consolidated description comparing the data from the literature with the experts' view.

The criterias used to identify the experts were experience, knowledge and background. The respondents were experts with large knowledge and experience in IM who used to work with IM in multinational companies recognized due to high performance in innovation. All of them are today working as consultant in their own enterprises.

The first informant has more than twenty-five years of experience as an executive in global company that has received innovation award at national level in Brazil. He is doctor in production engineering and used to be product and technology development director. He is currently business management consultant. In this research he will be called Expert A.

The second informant is global technology and product development manager in a northamerican company at United States. He has experience with technology development and innovation and he is master in mechanical engineering. In this research he will be called Expert B.

The third informant is master in engineering. He has more than ten years of experience as an innovation specialist and has worked in two companies that have received innovation awards at national level in Brazil. He is currently an innovation management consultant. In this research he will be called Expert C.

The fourth informant has more than ten years of experience in different companies that have received innovation award at the regional and national level in Brazil as IM specialist. Currently he is IM consultant and has supported more than thirty small and medium-sized enterprises in the implementation of IM process. In this article we will be called Expert D.

Finally the fifth informant has background in industrial design. He worked as industrial design and innovation manager for more than twenty-five years in a global company that has received innovation award at the national level in Brazil. Currently he is the Chief Executive Officer (CEO) in a small company of design and innovation. In this research he will be called Expert E.

A synthesis of the experts' background and experience is presented in the Table 2.

Table 2. Informant Profile.

Informant	Background	Experience
A	Doctor	Technology and Product Development Director
B	Master	Product Development Manager
C	Master	Innovation Management Specialist
D	Bachelor	Innovation Management Specialist
E	Bachelor	Industrial Design and Innovation Manager

3. Results

From the interviews an analysis was done in order to identify the main factors that influence IM performance comparing the literature with the point of view from the experts. A description of the experts' view for each factor is presented hereafter.

3.1. Innovation Strategy

All experts afirmed that innovation strategy is very important as it makes clear the desire of the organization to innovate and avoids the focus on cost and quality that most organizations have. Innovation strategy is the first step to be done to implement IM in an organization. Usually a diagnosis is done in order to know how the current innovation process looks like and if there is any good practice in use. The action plan to implement the IM process is developed from the diagnosis. The plan should be deployed to the whole organization considering budget, guidelines, responsabilities, scenarios and targets. The strategy also reflects in the projects prioritization. If the strategy is clear, prioritization is easier to set and the portfolio is built based on the main interests of the organization.

3.2. Culture

In a common sense the experts afirmed that innovation culture should be permeated through the whole organization, involving people from all the areas. At the beginning innovation can be restricted to a small group but the process should evolve in order to be disseminated to everybody. Radical innovation culture should be preferable to incremantal one.

The importance of a risk taking and error acceptance culture was detached, as well the value of diversity as a way to stimulate the idea generation process. Entrepreneurial capacity is also mentioned as a behaviour important regarding innovation culture. It means more autonomy to run innovation projects. Decision-making process should be decentralized and agile.

Inside culture aspects it was stated by all the experts that a recognition and reward policy is important, but it was not a consensus if it should be directly linked to the innovation results or as part of wider career plan. Recognition motivates people and improves the sense of accomplishment to participate in innovation projects.

People who work in the innovation process should be chosen according to their profile and trainings are fundamentals to permeate the innovation through the organization and contribute to the people commitment.

Individual who works with innovation must have knowledge, wide culture and long term vision.

3.3. Leadership

Leadership was cited by all the experts as a key point to engage people to participate in the innovation process. The sponsorship and support from the senior management is essential and it is considered the main success factor to IM implementation. As an example one expert cited the difficulties he faced at the beginning of the IM implementation process in the organization where he worked. Some directors had doubts about the financial return of the program and the support from the CEO was imperative to the continuity of IM implementation.

It was also pointed that the leadership should work in such a way to challenge the team to deliver outstanding results.

3.4. Organizational Structure

R&D was considered important to maintain the focus on innovation projects, since organizations many times prioritize cost reduction and quality improvement projects. But this area is not the unique responsible for innovation. The whole organization should be involved. The experts detached also that IM area should exist to manage the innovation process, but not necessarily to develop innovation.

Regardless the organizational structure, appropriate environmental conditions to develop innovation projects is necessary.

3.5. Knowledge Management

Experts pointed the importance of KM but afirmed that many organizations don't pay attention to and the result is to much rework and loss of knowledge. People should be stimulated to share knowledge between colleagues in order to keep the knowledge inside organization. And it's critical when an experienced professional leaves the company without sharing his knowledge.

They also detached the importance to have an information management system and some tools were mentioned like design guides and lessons learned reports. The problem is that there is a lack of discipline to fullfill information systems.

Anyway it is necessary to explain to the employees the importance of innovation as well to carry out training about the innovation skills required to run the process.

3.6. Resources

All the experts detached that human and finantial resources and infrastructure are indispensable for the innovation process. They mentioned also that to have a clear innovation strategy is important to obtain the required resources. There is no innovation without finantial, human and infrastructures resources.

3.7. Conceptualization

The importance in having a structured conceptualization process was cited by all the experts. It means that innovation projets are a result from consumer observation and environmental analysis, and also supported by new technologies. A structured process also results in a sustainable innovation over the time.

Regarding opportunities identification it was cited internal programs to generate ideas but it was pointed out that the most effective way to identify new opportunities are field visits in order to know the reality of customers. This process could be done through observation or direct conversation with customers, suppliers, service providers or service employees.

3.8. Technology Acquisition

Innovation can be a result from a technology development. In this way it is important to maintain external partnership with universities and suppliers as well to participate in congresses and fairs to be technology updated.

Even though innovation is more often pushed by technology, R&D and Marketing should work together in the innovation process.

3.9. Market Information

Market informations are fundamentals to the IM performance. Experts cited the importance to observe and talk to the consumers, as well market research. It was emphasized the need to construct partnerships and to look for opportunities outside the organization. As examples one expert cited the participation in congresses and fairs, partnership with universities and suppliers and market and technology trends analysis.

Marketing should monitor the innovation products in the market considering project goals and consumer perception and all these informations should be used as lessons learned for new projects.

3.10. Systems and Tools

System and tools needs were pointed by the experts in order to facilitate the innovation process. Systems that allow quick and easy access to information and a prioritization tool based on innovation strategy that considers technical, finantial and commercial viability of the projects are examples of systems and tools.

3.11. Product Portfolio

Product portfolio must be aligned with the innovation strategy, taking into consideration the main innovation projects. The analysis of the product portfolio can be considered as a priorization tool as it defines which innovation projects will be delivered to the market.

3.12. Project Management

Project management was cited by most experts, but they afirmed that few organizations take advantage of these tools. It consists on the management of all activities related to the development of innovation projetcs, including indicators and targets monitoring.

3.13. Commercialization

The result of innovation is linked to the return on investment or some form of value creation, either financial or otherwise, as brand or company image.

3.14. Framework comparing the main constructs with experts' view

As a result of this paper a framework comparing the experts' view and the factors that influence the IM performance from the literature shown in the Table 1 is developed. This framework is presented in the Table 3.

Table 3. Framework comparing experts' view and the factors that influence the IM performance.

Factor	Comparison between experts' view and literature
Innovation Strategy	Experts confirmed that innovation strategy is a key point and the first step of IM process. It should be linked to the organization strategy and deployed until operational level. It's also confirmed the importance of having clear innovation goals and that project priorization should be based on innovation strategy.
Culture	Innovation culture should be permeated through the whole organization. Experts confirmed the importance of having an error acceptance behaviour and a project autonomy with decentralized decision process. It's also identifies the need of a recognition and reward policy.
Leadership	Leadership is also considered as a key point. Senior leadership engagement is directed linked to people commitment and innovation results.

Factor	Comparison between experts' view and literature
Organizational Structure	Experts confirmed that innovation projects should be developed by multifunctional teams involving the whole organization. They detached the R&D importance and the need of an area to manage the innovation process.
Knowledge Management	The need of knowledge sharing is emphasized by the experts. Also they detached the importance of the communication between R&D and Marketing. Experts also cited the importance of KM and information management system and some tools like the design guides.
Resources	It was emphasized that human and finantial resources and infrastructure are indispensable.
Conceptualization	Experts confirmed the importance in having a structured innovation process.
Technology Acquisition	It was confirmed that R&D and Marketing should work together in order to have a portfolio aligned to the innovation strategy. Experts detached the importance of external partnerships and need of technological road map.
Market Information	Market informations are essential and consumer behaviour should be monitored.
Systems and Tools	Experts afirmed that easy to use systems and tools are essentia to facilitate innovation process.
Product Portfolio	Product portfolio fed by innovation projects and aligned with the innovation strategy were detached by experts as key point.
Project Management	Experts afirmed project management can provide a competitive advantage as few organizations take advantage of these tools.
Commercialization	Results should be monitored and can be considered as return on investment, value creation or brand image.

4. Final Considerations

The factors that influence the IM performance found in the literature were corroborated by experts' vision. Regarding organizationl factors the experts were unanimous in detaching the importance of considering the innovation in the company's strategy; that culture must permeate the entire organization; that leadership plays a key role; and that resources are essential. These are the main points highlighted by the experts.

In relation to the other organizational factors, it was shown that the R&D is an essential area, but not the unique responsible for innovation. The whole organization should be involved in the innovation process. Moreover, it was commented the importance of managing the innovation process, that can be done by an IM area or not. KM has been identified as a point to be improved. Even though it is considered important, many organizations don't pay attention to.

Factors related to the innovation process were less cited. The need to have a structured process is clear and the R&D area and marketing must work together. Market information and technology have been identified as necessary for the performance of innovation.

To conclude it is evident innovation results are linked to the return on investment or some way to create value, that can be financial or brand or company image.

As recommendation for futures works it is suggested a new search considering interviews with people who work with innovation in organizations with a well structured innovation processes.

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Interoperability Assessment Approach in Cancer Healthcare

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Abstract. Hospitals have constantly pursued quick, efficient, and quality services in order to fulfill customer/patient needs, thus causing improvement and innovation capability to be in tune with the processes executed. In general terms, services have been a big challenge to hospitals, once the current demand is not fulfilled. The appropriate management of processes and information flow greatly influence the operational performance of the involved hospital entities. Such integration and collaboration scenario promotes the identification of barriers to the organizational good performance, and regards interoperability perspectives an important assessment tool. This paper presents the IAMinCH - Interoperability Assessment Model for Cancer Healthcare domain, designed for the assessment of the interoperability capability in the cancer treatment sector, which is complex a analysis structure based on the AHP method, performance attributes deriving from different information sources are assessed and organized under the interoperability perspective. The results achieved enable a diagnostic view that better addresses the development of an improvement plan concerning the hospital interoperability capabilities in cancer healthcare.

Keywords. Interoperability. Process. Evaluation. Health Care.

Introduction

Currently, hospitals have faced a social and economic period characterized by higher demand and an increasing need for more and better communication, interaction, integration, and cooperation [1]. The healthcare continuous improvement, regarding information accessibility and efficient processes during hospitalization, requires a better information management as well as the cooperation among the parts involved in the healthcare process [2]. In this way, interoperability and its assessment has been employed as a tool for communication and process improvement and optimization in the healthcare area [3]. Literature brings several methods related to interoperability assessment [5]. Such methods cover different issues, contexts, and domains by means of different approaches. Many research papers [9][10][11] and initiatives have been proposed in order to identify interoperability dimensions and define a knowledge structured framework in the healthcare domain, e.g. Nehta, eHealth FEI – Framework Interoperability, Personal Health System - PHS [7][8][13]. But, a common however understanding and a consensus about such dimensions is still open nevertheless. This paper targets applying process mining through organizational mining in the healthcare

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processes in order to obtain knowledge on organizational flows, organizational structures and social network analysis among the organizational entities. In this paper, we describe process mining and organizational mining in section 1, section 2 provides a description of the mothodology proposed by this research, section 3 contains the case study applied at Erasto Gaertner Hospital and section 4 brings the conclusions.

1. Interoperability in Healthcare

Among the various definitions of interoperability, the most commonly employed is "the ability of two or more systems or components to exchange and make use of the information exchanged" [11]. In healthcare systems, interoperability is a key requisite to ensure service quality in a fast and efficient way. Healthcare demands hospital services characterized [13] by an appropriate coordination of processes and efficient information exchange among different systems. In such environment [3][5], people involved must fully understand these perspectives (information and processes), requiring an adequate organizational structure that includes technology and management perspectives in order to minimize the barriers to the good organizational performance, and aiming to optimize the interoperability capability [9][10]. Among the different interoperability models and frameworks found in literature, some are specifically related to healthcare [10]. The objective consists in providing an organization mechanism so that interoperability concepts and perspectives in a hospital environment are better structured and represented. Some of these frameworks are presented in a comparative chart, which will be the foundation to the knowledge organization and structural requisites for the conception of an interoperability assessment model. The first one belongs to the wider interoperability context, and are mentioned given their relevance in the present research context.

Developed on the INTEROP application – European Excellence Network [18], the **Framework for Enterprise Interoperability (FEI)** classifies and defines three interoperability dimensions: barriers, concerns, and approaches [4][5]. According to the FEI, the *interoperability barriers* refer to the removal of obstacles identified for the establishment of interoperability. Three types of barriers are identified: (i) *conceptual* – related to syntactic and semantic differences of information to be exchanged; (ii) *technological* – regarding the incompatibility of information technologies; and (iii) *organizational* – related to the organizational and management structure employed by enterprises. *Interoperability concerns* refer to the diagnosis or establishment of interoperability at different operational levels. (i) *data* interoperability; (ii) *service* interoperability – concerning the identification, composition, and execution of several applications/services (independently conceived and implemented); (iii) *process* interoperability – regarding the coordination of processes; and (iv) *business* interoperability – referring to the organizational structure, models, and business rules.

The **E-Health Interoperability Framework** [13] was developed by the National E-Health Transition Authority (NEHTA), Australia. It illustrates the definition of three interoperability perspectives oriented to healthcare organizations – organizational, informational, and technical. The *organizational* perspective comprehends the shared information policy and process structure aspects as well as business rules. This perspective includes business, security policies, and privacy. The *informational* perspective regards shared structures of semantic creation based on information interchange [13]. The *technical* perspective refers to the connectivity of data exchange systems and the use of services. The **Health Information Systems Interoperability framework (HIS)** [19] is a reference framework created by the ASIP Santé (Agence Nationale des Systèmes d'Information Partagés de Santé) [19] aiming to promote the development of services for the electronic exchange of personal healthcare information and for the creation of interoperability conditions among HIS systems that meet privacy and security requisites. This reference framework specifies the standards to be employed in the exchange of personal healthcare information via systems. In addition, the model depicts the execution procedure of these standards so as to enable the development of interoperability among HIS systems in accordance with the privacy and security requisites [19]. This **Personal Health System (PHS)** [20] reference consists in supporting the supply of continuous quality control services as well as the supply of customized services, regardless the location of the person [20]. The PHS Interoperability Framework (PHS IF can be included in two minor structures: (i) technical and execution structure, including rules, profiles, and directions with regard to its implementation based on the usage background of the designed business, identification, and authentication tools, security protocols, essays and certification; (ii) an organizational chart and political issues, governance, legal aspects and regulations, such as data protection and responsibility. Table 1 shows the comparison between the frameworks presented. The assessment is founded on the interoperability dimensions defined by the FEI, which points out its extensibility to the hospital domain in the assessment of organizational and business perspectives [4]. The use of such structure as assessment base for different application domains is corroborated by literature, such as in [2] [9] [21] [22] [23]. In the construction literature there is no model that considers three different informational sources in the multi-criteria evaluation model evaluation capability for interoperability, thus evidenced the comparative models for applicability in Hospital Domain.

Table 1. Comparative Interoperability Overview.

	EIF	Ehealth	HIS	PHS
	Overview			
Interoperability dimensions	*Organizational *Technical *Semantic	*Legal *Organizational *Technical	*Semantic *Technical	*Organizational *Technical
	Interoperability Barriers			
Technological	●	●	●	●
Conceptual	●	◐	●	○
Organizational	●	◐		●
	Interoperability Concerns			
Business	◐	●		◐
Process	●	●	◐	●
Service	◐	○	●	●
Data	●	◐	●	◐

Assessment makes use of the following notations:
● High concern - model criteria fulfillment.
◐ Medium concern - partial fulfillment of criteria
○ Low concern - minimal fulfillment of criteria
' ' No concern – no fulfillment or approach to the criteria

2. Interoperability Assessment Model For Cancer Healthcare Domain - IAMinCH

The interoperability improvement implies in the need to define assessment metrics. Measuring or assessing interoperability allows the identification of weaknesses and strengths faced by enterprises or hospitals in order to interoperate, and thus prioritize improvement actions [10]. In literature [15], it is possible to find a number interoperability assessment models and methodologies, comprising both quantitative and qualitative approaches under the different perspectives pointed out by the different Interoperability Frameworks (IF) and considering the organization's temporal and contextual positioning.The comparative chart (Table 1) highlights the adaptation of the FEI and EIF frameworks to the healthcare domain, corroborated by the authors in [9], who state that both IFs constitute a general framework for business interoperability and it can be applied to a healthcare enterprise. According to Chen [4][5], the interoperability diagnosis or establishment consists of the identification of different operational levels of an enterprise, therefore allowing the conceptual adaptation to a hospital based on the perspectives and barriers identified in the presented frameworks.

Through the views representation [3] associated with the barriers (conceptual, technological, and organizational), the model becomes complete and may represent the hospital structure, detailing perspectives such as: business, process management, policies and procedures, HR, IT, and semantics. Regarding this conceptual structure, the development of an assessment model strategy is proposed, the IAMinCH – Interoperability Assessment Model for Cancer Healthcare domain. Such strategy is shown in Figure 1, illustrating the path followed and the strategy for the interoperability measurement final objective suported by the IAMinCH. The hospital is presented as the application domain, focusing on the declared processes of the oncology sector.

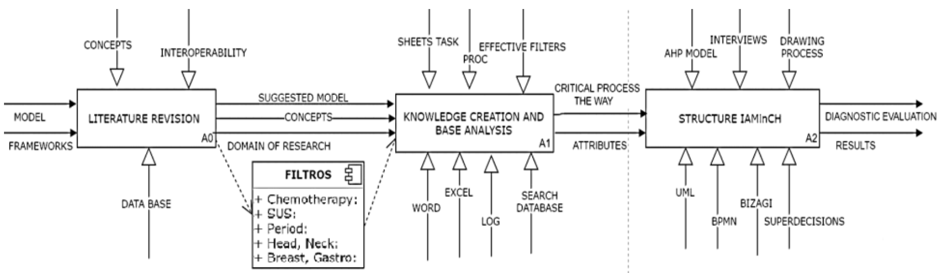


Figure 1. IAMinCH development framework.

Steps from A0 to A2 (Figure 1) based on the IDEF0 notation [6], illustrate the knowledge development and organization inherent to the hospital context, so as to reveal and raise the interoperability domain attributes related to the oncology process, and provide structural subsides to the IAMinCH construction. Step A0 regards the literature review, considering models and frameworks related to interoperability as input and the model proposed with the identification and filter of the domain to be used as output. The “Filters” component (from component A0 to A1) represents a scope delimitation regarding the oncology processes. In this way, they are considered as the most critical (known as “lifeline”) and relevant in the performance assessment and interoperability requisites. The amount of information shared within the processes is above one thousand and the number of possible routes in the hospital processes flow is very high. In this way, the lifeline of the cancer treatment process is obtained, delimiting to Chemotherapy and the instances indicated by the ‘Filters’ component in Figure 4 (SUS - Unified Health System, head/neck, breast/gastric). The A1 component is responsible for the knowledge organization and the analysis base formation based on the information sources: task sheets (specialist declared description of the executed processes), PROCs (institutional normative reference), and execution registers of the management systems (logs). The awareness of the critical path and qualification attributes of the assessment domain supports step A2 in the structural development and assessment model usage based on the AHP (Analytic Hierarchic Process) multi-criteria assessment method, the IAMinCH. As a result, a diagnostic assessment of the attributes capability and interoperability levels related to the oncology processes at the hospital is obtained. A more detailed analysis of steps A1 and A2 in the framework (Figure 1) is presented next.

2.1. Step A1 - Analysis base and atributes

The data surveying step of relevant information to the operational performance assessment, under the interoperability perspective, is characterized by the need to identify qualifying attributes. In the scope of this paper, attribute refers to what is inherent to something, such as characteristics, classes, and variables that allow the organization to make remarks and be able to assess and achieve interoperability in the hospital context. Guidelines refer to the attribute through business rules established by the hospital model. Three stages for the surveying of attributes and guidelines were carried out culminating in the IAMinCH structural specification. In the **First Stage** filters were defined, given the complexity and size of a hospital with regard to the amount of information shared within its processes. Inspired by Chalmeta [3] and Espadinha [24], such filters refer to an identification process for critical paths, which considers the amount of information and intra-sectorial coordination of processes through a matrix and relational inference. As a result, filters defined-leading processes related to Oncology reception sector: (i) new patients; (ii) SUS referred (Unified Health System); (iii) under cancer suspicion; (iv) breast, head, neck, and gastric; the 30-day period was considered. Based on the scope resulting from the filters applied in the first stage, information surveying characterizes the **Second Stage**. As previously highlighted, the focal perspective of hospital processes led us to a triple information source deriving from this perspective. They are: (i) PROCs – internal procedures of the hospital, conceived under the light of international recommendations for cancer treatment; (ii) TSs – Task Sheets, register and assessment artifact of the processes executed and declared by the involved parts; and (iii) LOG registers generated by the hospital management and information system.

The **Hospital Internal Procedures (PROCs)** This document stores the procedures that must be executed by sectors and departments during the hospital work shift. This description of procedures is characterized by steps, each interaction of the responsible by the process, what interactions are executed, and who executed them (responsible by the execution). Such reference permits the identification of interaction between processes and sectors, systems, and people. The associated information flow interacts along the process path with sectors; such interactions can be electronic and physical information exchange (patient prompt, healthcare card), procedures (stamp, signature). Therefore, the PROCs represent procedural reference models, providing a number of attributfes and information forwarded or exchanged with sectors involved in the process. The **Task Sheets (TSs)** are artifacts developed in order to collect information about the process flow, making use of interviews (process declared knowledge). In the present paper, the purpose of the TS consists in providing the foundation to analysis of attributes, through the assessment of the process executed (declared) in accordance with those described in the PROCs. The fields in the TS corroborate with the data survey registered in the PROCs, in addition to fields to register the possible interactions with departments and among systemic processes, either dependent from the information system or not. não. Thus, assessment attributes are identified, and their fulfillment during the process flow is checked, being the base for measuring the interoperability level. In this way, making it possible to evaluate the fulfillment potential of the attributes identified by the sector in the internal procedures (PROCs). The task sheet must be approved by the professionals involved in the process, thus providing the tool with an approval from the declared process. The hospital associated with the development of this paper employs an information and management system called Tasy. The system main focus resides in fulfilling and managing information so that the patient is easily admitted and identified within the hospital environment. In the system database, the patient information and prompt are stored for internal and, sometimes, external access. These data are stored during the patient admission process and are used in all sectors and departments, demonstrating the inherent complexity present in the fulfillment of interoperability requisites.

The Third Stage consists in analyzing and conciliating information derived from previous stages (information sources) as well as organizing knowledge obtained from the attribute definition base. The organization structure obtained from these attributes must be supported by the IAMinCH assessment method, permitting the issuing of a diagnosis of the existing interoperability level with regard to the critical path related to oncology processes. In order to support this modeling process of the assessment knowledge, a relational matrix inspired in the IACM model (Interoperability Attributes Correlation Matrix) [25] is proposed in. The matrix indicated in Figure 2 focuses on the correlation analysis of the involved domain attributes with the interoperability perspectives (Business, Process, Service, Data). The positioning of the attributes in the interoperability quadrants permits the categorization required for the assessment organizational structuring adopted by the AHP method. The relational matrix was generated with the attributes found in the TSs and considered as the most important ones. Additionally, the importance of each attribute was assessed according to the *interoperability concerns* referring to the interoperability diagnosis or the establishment inspired by the Frameworks under study. In such assessment only Business, Process, Service, and Data were considered, once these views are merged in the Oncology sector. As an example of assessment, the attribute "*Request/APAC Search*" is described as a budget request to the Unified Health System (SUS), thus placing more importance on the Business aspect. It means that if the APAC is not appropriately executed, it may have a relevant impact on the Business aspect.

	Communication SUS	Solicitation APAC	Register	Schedules	Records in Evolution - PEP	Consultation and Screening	Exams	Infusion Chemotherapy	Communication hospital patient	Process Registration - PROCS	Medication administration	Guidelines patient	intersectoral communication	Release Status APAC	Administrative Supervision		Importance (%)
Business	9	9	1	3	1	1	3	1	9	9	3	3	9	9	9		25
Process	3	3	9	9	3	9	3	9	3	9	9	3	3	1	9		25
Service	3	3	3	3	3	9	9	9	9	3	3	9	3	1	3		25
Data	9	1	9	9	9	3	9	3	9	9	3	9	9	9	9		25
Degree of importance (Req. Product)	600	400	550	600	400	550	600	550	750	750	450	600	600	500	750	8650	100
Percentage	6,94	4,62	6,36	6,94	4,62	6,36	6,94	6,36	8,67	8,67	5,20	6,94	6,94	5,78	8,67	100	

Figure 2. Matrix relational HealthCare.

2.2. Step A2 - IAMinCH Structure

The IAMinCH structure (Interoperability Assessment Model in Cancer Healthcare) was developed as an assessment model for interoperability in the healthcare domain. This structure assesses the attributes established by arranging them according to the AHP -

Analytical Hierarchy Process method. Given to subjective or intuitive considerations that suggest the relational assessment of different criteria (attributes), the AHP is particularly appropriate to the healthcare specific scenario and the assessment of the existing interoperability potential in the considered domain. The employment of the AHP begins with the problem breakdown within a hierarchy of criteria (categories) that are more easily and independently compared. After creating such criteria, the decision makers comparatively evaluate the alternatives, considering each of the criteria, i.e., fulfilled, partially fulfilled, and not fulfilled. This assessment determines the alternative probability to meet the established target. The higher the probability, the more expressively it contributes to the final objective (interoperability level). Figure 3 illustrates the structure AHP for evaluation problem modeling, consisting of 4 levels. The first (EIA - Enterprise Interoperability Assessment) refers to the goal of assessment of potential interoperability in the hospital sector oncology; the second (Criteria) considered the criteria represented by the prospects (concerns and aspects) interoperability (Business, Process, Service, Data); the third (Attributes) represent the attributes organized in quadrants (Figure 2); the fower level (Level / Maturity) identifies the potential for interoperability of Oncology through the maturity level diagnosis.

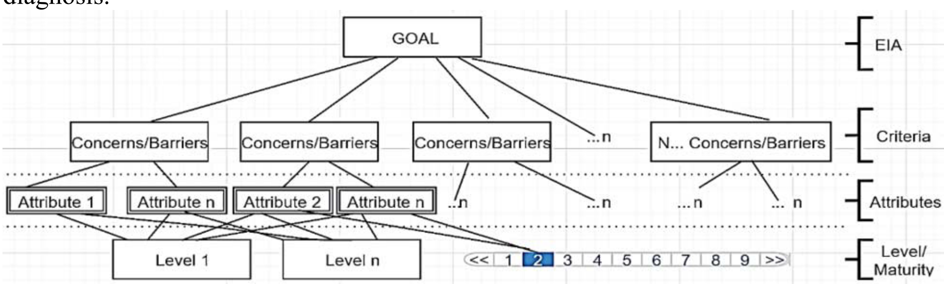


Figure 3. AHP Structure of the IAMinCH.

3. Application Case

The IAMinCH was carried out application in a hospital located in Curitiba – Brazil having as mission “fighting against cancer with humanism, science, and care”. The hospital is a reference in cancer prevention, diagnosis, treatment, and research in southern Brazil. An average of 1366 patients are admitted at the hospital every day, most of them in the Oncology. By using Task Sheets and PROCs it was possible to identify the assessment attributes and their structuring and organization through the relational matrix (Figure 2). The identification of the process critical path enables the definition of the involved sectors and, therefore, determine the interoperation potential assessment domain of the involved entities. Stages and components described in Figures 4 and 5 lead to IAMinCH development in Super Decisions Platform for diagnosis. The are presented as follows.

Based on the Task Sheets and PROCs, attributes indicated in Table 2 were obtained the raised attributes in order to measure compliance, Figure 4 ilustrates the information flow between the process actors highlighting the related attributes. The task sheet selected was sheet number 05. This task sheet describes the activities in the Nursing sector. The goal of this sector consists in advising the patient with regard to the treatment on course, providing information such as side effects, duration of chemotherapy sessions, intervals, and cycles. This sector become crucial for the establishment of attributes and due to the amount of associated information and relations. PROC was selected as support to the knowledge base construction for interoperability assessment.

Table 2. List of extracted attributes.

	IN	FOR	INFORMATION
A1 RECORDS	NURSE	TASY	RECORDS ON LINE
A2 CUSTOMER INF	NURSE	PATIENT	CHECK LIST QUIMIO
A3 LEADING	PATIENT	PAPEL FÍSICO	LEADING
A4 AFFIRMATION	PATIENT	CLINICAL	RECEIVED VIA SIGNED GUIDANCE
A5 EVOLUTION	NURSE	RECORDS	STORING DOCUMENT SIGNED
A6 RULE APAC	NURSE	E-health	APAC APPROVAL OF CONSULTATION
A7 SCHEDULING	NURSE	TASY	SCHEDULING CHEMOTHERAPY
A8 TEST	NURSE	TASY	CHECKS EXAMINATION

Based on the relational matriz in Figure 2 and the AHP hierarchical structure indicated in Figure 3, the IAMinCH structure is executed on the Super Decisions platform. The decision makers comparatively evaluate the alternatives according to each of the criteria. The hierarchy structural defines through a pertinence assessment of each attribute, its interoperability quadrant. By applying the methodology, it is possible to determine the importance of each Criterion/Concern on each alternative (fulfillment level). Also, the importance of each criterion and attribute on the overall objective is verified, which consists in determining the potential level of interoperability of defined heath care.

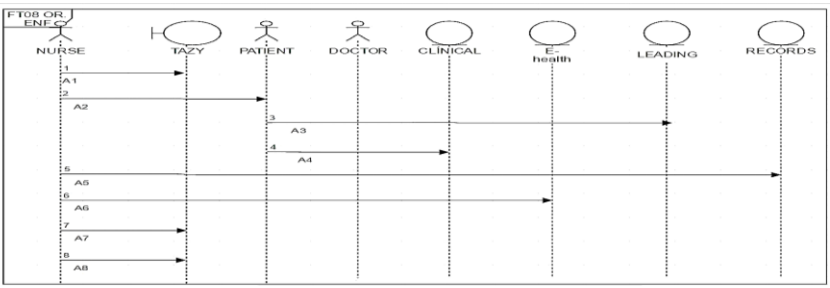
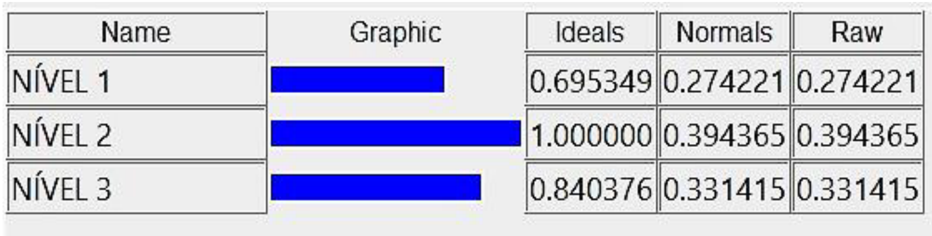


Figure 4. Process Path and Establishment of Attributes.

Table 3 shows that most attributes present partial partial capabilities in the Oncology sector with regard to the hospital. This means an interoperability level remained at level 2, as in Figure 4. From this diagnosis view, interoperability barriers could be identified and an improvement plan carried out by the Hospital.

Table 3. Effective/Potential Interoperability Analysis.

	Interoperability Concerns				Interoperability Approaches		
Atributes	Business	Process	Service	Data	Attended	Partial	Not Attended
A1 RECORDS	x		xx	xx	x		
A2 CUSTOMER INF	xx					x	
A3 LEADING	x	xx	x			x	
A4 AFFIRMATION	x	x	x			x	
A5 EVOLUTION			x	x		x	
A6 RULE APAC	x						x
A7 SCHEDULING	x	x	x			x	
A8 TEST							x



Name	Graphic	Ideals	Normals	Raw
NÍVEL 1		0.695349	0.274221	0.274221
NÍVEL 2		1.000000	0.394365	0.394365
NÍVEL 3		0.840376	0.331415	0.331415

Figure 5. Potential/Result Interoperability.

4. Final Considerations

Hospitals have faced a higher demand than their overall service capability, evincing their increasing need to improve communication, interaction, cooperation, and processes. The hospital organizational performance finds in the interoperability perspectives an important assessment tool. This paper focused on the oncology sector due to its complexity and importance to the hospital. In this way, a diagnostic assessment of the attributes capability levels as well as the hospital interoperability level related to oncology processes have an applicable value. The use of the proposed IAMinCH assessment method allowed the diagnosis of the interoperability level existing in the critical path sphere regarding oncology processes employing the data collection stages, the existing policies, and information systems. The AHP allows the problem space structuring with regard to task sheets (TSs) and PROCs, thus identifying the progress of attributes in relation to the potential interoperability. After the execution of the IAMinCH, it was identified that the interoperability potential in the oncology sector is being partially fulfilled. The proposed framework and its developing cycle, supporting a knowledge identification and its modeling through a decision analysis method (AHP) brought adequate interoperability assessment requirements in Health Care, dealing with imprecise, qualitative and tacit knowledge.

In future work, the application of new MCDA methods (multi-criteria decision analysis) to new cases in the healthcare field will be investigated. More specifically, the Electre TRI method will be highlighted, given that it allows a more refined assessment definition of each criterion, and thus the consideration of quantitative intervals – appropriate to the use of metrics stemming from registers of the hospital management systems through the employment of processes mining.

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Developing BIM Culture in a University – Past and Future Steps

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Abstract. Building information modelling (BIM) still faces adoption barriers in the Architecture, Engineering and Construction industry (AEC). One of the barriers perceived in literature was the lack of professionals with knowledge and BIM competences developed, also due to the fact that BIM is not commonly taught in universities yet, especially in Brazil. Through a case study, this paper analyzed one university that developed a BIM research culture in its curriculum. The study identified a set of three steps to implement a BIM culture in the university: Hiring lecturers and professors with BIM knowledge, creation of a BIM class and the development of a BIM research culture in undergraduate levels. Then, three further steps were suggested to widespread and deepen the use, study and research of BIM in the university: Further capacitation of professors and lecturers, develop BIM research groups and advance post-graduate research and the insertion of BIM concepts in other subjects. A questionnaire sent to the professors and course coordinators involved with the process corroborated the steps perceived through document analysis.

Keywords. BIM, engineering, barriers, university adoption.

Introduction

BIM can be defined as a modeling technology and associated set of processes to produce, communicate, and analyze building models [1]. The design and project processes in the AEC industry have evolved significantly in the last years. Primitive techniques evolved to technical drawings with the use of paper. More recently, the use of computers accelerated the process going from 2D CAD systems to 3D modeling, and nowadays reaching Building Information Modeling systems. This process of technological evolution should be thought in the universities, so students are aware of techniques and understand their differences, since sometimes there is confusion related to what is BIM exactly [2]. This technological evolutionary process, as well as the characteristics of the methods are described in Figure 1.

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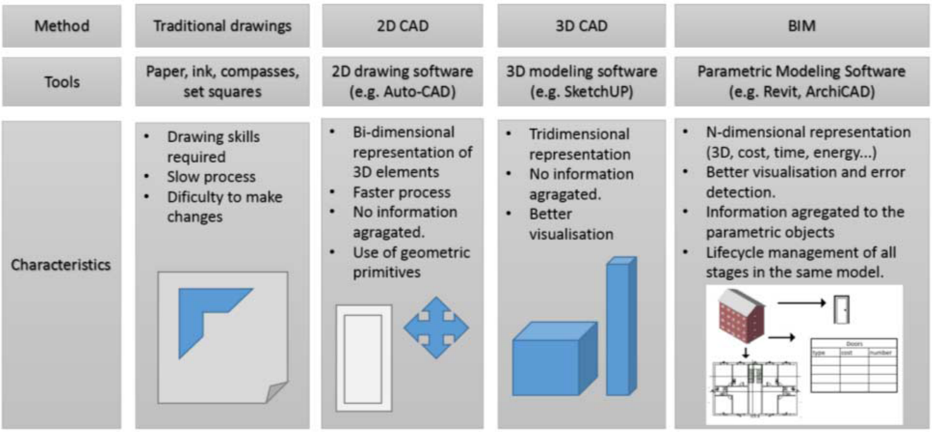
New technologies, however, tend to face some adoption barriers [3]. Authors describe the adoption barriers for BIM in two categories: management barriers and training barriers. Among the training barriers, literature highlights that BIM was not often thought in the universities, so young engineers and architects were not aware of the new technologies [4][5].



Method	Traditional drawings	2D CAD	3D CAD	BIM
Tools	Paper, ink, compasses, set squares	2D drawing software (e.g. Auto-CAD)	3D modeling software (e.g. SketchUP)	Parametric Modeling Software (e.g. Revit, ArchiCAD)
Characteristics	• Drawing skills required • Slow process • Dificulty to make changes	• Bi-dimensional representation of 3D elements • Faster process • No information agragated. • Use of geometric primitives	• Tridimensional representation • No information agragated. • Better visualisation	• N-dimensional representation (3D, cost, time, energy...) • Better visualisation and error detection. • Information agregated to the parametric objects • Lifecycle management of all stages in the same model.

Figure 1. The evolution of design and project methods according to [2].

1. BIM adoption barriers

BIM adoption barriers by companies can be divided in two main categories: project management barriers and training barriers [3]. Most adoption barriers related to project management are related to the lack of knowledge of the technology and to the difficulties of altering the project and design processes in the companies. The main barriers are:

- The choice of the software and platforms is a common problem, since professionals often have difficulties choosing the software or platform that best suits their office [5] [3][6].
- The belief that BIM is only a 3D modelling tool is also a barrier, causing the involved not to understand its potential [3].
- The lack of interoperability is another difficulty faced by AEC industries. The unreliability of interoperability among some systems may lead users to second-guess the advantages of the use of BIM [7].
- The changes in the workflow also cause some challenges, since BIM projects need more personnel allocated in the early phases of the project, in contrast with 2D CAD, which tends to allocate more workers on the detailing stages [3][6].
- Risk management can also be an issue. Excessive worries that the pilot project may not be completed may lead companies to waste too much time on a plan B, leading to a demotivation with the new system [3].

Authors also highlight training barriers. Difficulties in training and capacitation may lead to difficulties in the adoption processes of BIM technologies. The main ones, according to the literature are:

- Traditional CAD use. Traditional CAD users are often more resistant and have bigger difficulties understanding and using BIM than users who have never used CAD before [3].
- The need for differentiated training may become an issue. All employees must receive BIM training, however this training should be specific to the employee's function. Also, when new employees are hired, these too must receive BIM training, in order to keep the team homogeneous [3].
- Few universities teach BIM, especially considering the Brazilian reality, so young professionals reach the market without BIM vision [4][5] .

Literature states the importance of formal training, due to BIM´s complexity [8]. Other authors also observe that software companies usually help in the adoption process by providing free or cheaper software licenses for professors and students [9].

Nine BIM player groups involved in adoption processes were identified: policy makers, construction organizations, individual practitioners, technology developers, technology service providers, industry associations, communities of practice, technology advocates and educational institutions. The main role of educational institutions such as universities and other learning institutions is to develop and deliver educational programs and related material for BIM learners [10].

Along with the actors, literature also identifies nine important actions for BIM diffusion. These actions are: make aware, encourage, observe, educate, incentivize, track, prescribe, enforce and control. Universities can play an important part in these actions. Through teaching, universities can participate in creating awareness and educating. Also, through research, universities may participate by observing and tracking [10].

Some initiatives are being developed to initiate BIM teaching in Brazil, however, scholars highlight that the BIM teaching in Brazil may still be immature, especially if compared to the counterparts in other countries, mainly due to the lack of integration between AEC subjects [4][5].

Another barrier to BIM adoption in Brazil may be related to the difficulties in interoperability for national programs, especially since structural designers in Brazil tend to use software adapted to Brazilian regulations. These barriers in interoperability lie mainly in data and formats, creating difficulties in the entire process for BIM use [7].

2. BIM competences and capacitation

Professionals may acquire a certain set of skills or competences in BIM through three main channels. Competences may be acquired though formal education (usually focused on theoretical knowledge), through on-the-job training (focused on skill improvement) or through professional development (focused on improving personal traits) [11].

Authors also cataloged eight BIM domain competences:

- Managerial: decision-making abilities, to determine or select long-term strategies.

- Functional: non-technical abilities to initiate manage and deliver projects.
- Technical: abilities needed to generate project deliverables such as modelling, model management, drafting, etc.
- Supportive: competencies used to maintain information systems and communication technologies.
- Administrative: skills needed to fulfil and maintain organizational goals.
- Operational: related to the activities required to deliver a project or part of a project such as designing, analyzing, simulating and estimating.
- Implementative: abilities related to the activities necessary to introduce concepts and tools into an organization (component development, library management and standardization).
- Research and Development: competence connected to the activities linked to knowledge engineering, research and coaching.

BIM teaching can't only be seen as an end in itself, but also as a powerful teaching tool. Since BIM is an environment that allows many kinds of simulations, it can be used as a teaching tool to teach project management using real world scenarios. It was shown to be very effective, especially when compared to more traditional methods [12].

Barison and Santos [5], divide BIM functional competences in three levels: BIM Modeler/facilitator, BIM analyst and BIM Manager. The authors recommend that the teaching methodology should be developed for each particular type of BIM professional. Literature also highlights the importance of not only teaching BIM, but promoting BIM in the AEC industry as well.

3. Methodological Approach

Observing this scenario, the research question emerges as: "how can a university implement BIM teaching?" This paper proposes to shed some light in the manner of how to implement BIM teaching in a university.

The object of this study was the adoption of BIM as a teaching and research tool in the Polytechnic School of a Brazilian university. The university studied is located in the South of Brazil, in Curitiba, the capital of the state of Paraná. The Polytechnic school is composed of engineering, informatics and other technology courses, as well as post-graduation and extension courses in these areas.

The case study was conducted in two stages. The first stage was conducted through document analysis. The documents analyzed were: professors' and lecturers' CVs, classes' syllabus, course completion projects developed by students, research papers and classes' diaries. Through this analysis, three first steps for BIM adoption in the university were identified, as well as three future steps were suggested to develop even further BIM adoption in universities. The steps are described in figure 2.

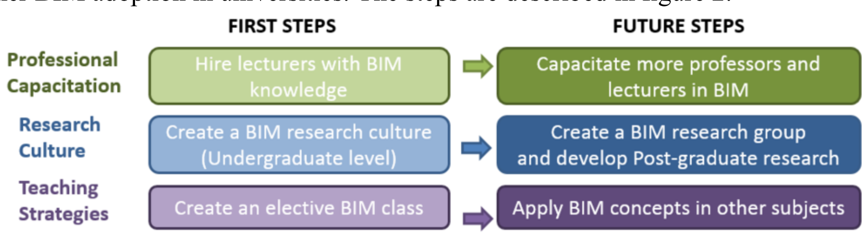


Figure 2. BIM adoption steps in the university.

After the documental analysis, a questionnaire was sent to professors, lecturers and coordinators involved in the adoption process. This was done to validate the past and future steps perceived.

The professors were asked to rate the steps in a Likert scale according to their perception of importance of these steps to the process for BIM adoption (the scale was divided in: not important, somewhat important, important, very important and extremely important). The questionnaire was sent through institutional e-mail, and recorded via Qualtrics. The professors also answered open questions, in which they were asked if they perceived any other important step in the process different from those listed.

4. BIM adoption first steps

In the first stage of document analysis, three main areas were identified in the adoption process of BIM in the university, and in this areas a specific step was perceived. They are:

- Staff capacitation: Hiring professors and lecturers with BIM knowledge ;
- Development of a BIM research culture: Stimulating students to develop undergraduate research in BIM (especially for course completion projects);
- Teaching: Developing a BIM subject for undergraduate students;

The steps perceived showed connection among each other. The development in one area, created momentum for the development in the other two sectors, since we can perceive an increment in the numbers of students taking the courses, staff capacitation and conclusion projects written by undergraduates within the last five years.

These first steps are described in detail in section 4.1 through 4.3.

4.1 Valuing BIM capacitation in professors and lecturers

Hiring staff with BIM knowledge and background is an important step in BIM adoption in a university.

In order to teach a BIM subject and aid the development of a BIM culture in the university studied, lecturers usually have majors in civil engineering or architecture, and some practical experience, especially in the project area.

These lecturers are usually required to have at least a master course, and frequently have already developed research in the area.

In the last five years the university hired three professionals with extensive BIM background. Two of them had developed research in BIM for their master´s dissertations, and the third had used BIM in the professional environment. All of them lectured and worked previously with steel or cast-in-place concrete structures.

The contact with these professors allowed the development of a BIM research culture, as they worked as advisors for course completion projects. These professionals also helped to raise awareness among the students about the existence of new BIM technologies. Finally, they helped to develop and teach a BIM discipline.

4.2 Developing a BIM research culture

In the process of developing a BIM research culture, the university stimulated the development of course completion projects by undergraduate students using BIM as a tool or by having BIM as a subject of study.

In the last five years, students of Civil engineering in the university in question developed at least ten conclusion projects containing the word BIM in their title or summary.

As seen in Table 1, the number of conclusion projects has increased in later years. This is probably due to the growing interest of students in the topic.

Table 1. Course completion projects developed by undergraduate Civil Engineering students.

Year	Conclusion projects developed
2015	BIM Manager characterization BIM interoperability for cast-in-place concrete structures Development of a cast-in-place concrete structural library
2014	Case study of foundation analysis through BIM Project compatibilization through BIM Building planning aided by BIM Comparative of BIM and 2D CAD: uses in construction cost studies
2013	Project information compatibilization through BIM BIM for concrete structures: reinforcing bars
2012	BIM and pre-cast concrete structures
2011	Impact of BIM in the project and planning processes

4.3 Offering BIM subjects

A subject called Building Information Modelling was offered in a post-graduation specialization course in 2013. Based on this subject, a study plan for the regular BIM classes at graduation level was developed (Figure 3).

Observing the course curriculum, it can be perceived that it was structured in four main competences, which contemplate most of Succar et al. (2013) [11] BIM competences:

- Being able to differentiate BIM and other CAD systems - Managerial competences;
- Creating building models using a BIM software - Functional, technical and operational competences;
- Generating and detailing construction documentation - Implementation competences;
- Understanding interoperability and generating IFC files. - Research and development competences.

In the first semester of 2015, the subject was finally offered to students in the regular civil engineering undergraduate course as an elective subject for the fifth period. Six classes were offered, one of them being an international class. This international class was taught in English, which is not the first language in Brazil. In the second semester the scenario repeated itself, almost identically, with one less group being offered.

The number of regular classes probably decreased in the second semester of 2015 due to difference in the number of students that were coursing the semester at the time, probably not meaning a loss of interest or any other factor, since the number of groups rose again in 2016.

The results can be seen in Table 2.

Table 2. Number of groups taking a BIM subject.

Semester	Number of regular groups	Number of international groups
1st Semester 2015	5	1
2nd semester 2015	4	1
1st semester 2016	8	1

PUCPR GRUPO MARISTA	**Pontifícia Universidade Católica do Paraná** **Politechnic School** **Civil Engineering**
COURSE TITLE: Building information modeling	
HOURS: 2 hours/week	**SEMESTER: Elective – suggested: Third semester**
PREREQUISITS: This subject is intended chiefly for Civil engineering e Architecture Students. Electrical and Mechanical engineering students might also profit from the course.	
DESCRIPTION: Building information Modeling, Object modeling, predecessor design technics and interoperability through IFC.	
COMPETENCES	
1. Being able to differentiate BIM and other CAD systems.	
2. Creating building models using a BIM software.	
3. Generating and detail construction documentation.	
4. Understanding interoperability and generating IFC files.	
STUDY TOPICS	**RELATED COMPETENCES**
Introduction on CAD BIM concepts and history, main differences between the software and choosing the right software for each project.	1
Building Modeling.	2
Parametric object modeling.	2
Generation and alteration of tables and drawings.	3
Interoperability and IFC.	4
METHODOLOGY: Practical assignments 50% + Theoretical assignments and presentation 50%	
EVALUATION ACTIVITIES: Practical assignments and/or written tests.	

Figure 3. Course Plan for Building Information Modelling.

5. BIM adoption future steps

The process of technological adoption, in this case BIM, can´t be considered finished simply by teaching students BIM concepts. BIM in the university, just as in the AEC industry, should permeate all different areas and sectors, and this mindset assumes a constant technological evolution. In order to widespread BIM use, some future steps for BIM adoption are suggested in the following sections.

Again, these steps are divided in the three identified BIM areas: Staff capacitation, research and teaching strategies.

5.1 Capacitating more professors and lecturers in BIM

To achieve a wider BIM adoption in the university, it is necessary that other professors and lecturers learn BIM at some extent. Either at a more technical level through workshops and courses or in a more formal environment, through academic means (in doctoral or master courses).

Currently the university offers incentives such as scholarships for many kinds of academic development, however there are no short-term BIM courses or workshops available for professors at the moment.

This step is important for a wider adoption. If more professors receive BIM capacitation, BIM concepts can be applied in integrated projects or in different subjects other then only a specific modeling class.

5.2 Developing a wider research culture in the university

Higher-level research in BIM, especially in post-graduate levels, is essential for the development of a BIM culture. This could bring benefits not only to the university, but also to BIM users in general, considering benefits that specific researches could bring to the community.

Research in BIM is only recently starting to grow in the studied university. Some papers were published or are being developed in the subject along with PPGEPS (Program of Post-graduation in Production Engineering and Systems), mainly in the area of BIM interoperability, like the project "Interoperability Assessment for Building Information Modelling" [7] developed in 2014-2015.

The university could also profit from a BIM research group, to organize and unite researchers in post-graduate and undergraduate levels.

5.3 Applying BIM concepts in other subjects

The idea of BIM itself considers the use of the technology not only as stand-alone programs, but as an integrated process in which many construction disciplines can interact with each other [1]. Considering this view, BIM could be used to integrate disciplines in the curriculum for courses such as civil engineering and architecture.

This was proven advantageous in teaching. Since BIM involves many disciplines, teaching construction project management with BIM support was successful, especially due to the possibility of examining many areas in one single model [12].

6. Validation

Questionnaires were sent to two professors and two coordinators involved in the BIM adoption process. The goal of this stage was to validate the steps perceived in the documental research.

First, professionals were asked about their perception on the importance of each of the first steps: Hiring lecturers and professors with BIM knowledge, development of a BIM research culture in undergraduate levels and hiring lecturers and professors with BIM knowledge.

Then, they were asked about their perception of the importance of each of the future steps: Capacitation of more professors and lecturers in BIM, inclusion of BIM concepts in other disciplines and development of further research in BIM (post-graduate level and study groups).

The questionnaires contained the past and future steps and the folowing scale: 1- Not important, 2– somewhat important, 3 – important, 4 – very important, 5 – Extremely important.

According to the professors, from the first steps, the most important action perceived was the creation of a BIM class, followed by the development of a BIM research culture in undergraduate levels and hiring lecturers and professors with BIM knowledge. All steps were on average evaluated either as important, very important or extremely important. This is shown in table 3.

Table 3. Perception of the importance of the first adoption steps.

Step	Perceived average importance
Creation of a BIM class	Between very important and extremely important
Development of a BIM research culture in undergraduate levels	Between important and very important
Hiring lecturers and professors with BIM knowledge.	Between important and very important

From the future steps, the most important step perceived by the professors was the capacitation of more professors in BIM. Followed by the inclusion of BIM concepts in more disciplines and the development of further research in BIM (post-graduate level and study groups). This is shown in table 4.

These steps are slowly being developed, with some professionals seeking further capacitation and developing research in this area in the university. Some professors who answered the questionnaire even mentioned that the students themselves are applying BIM concepts in different subjects such as hydraulic or electrical projects.

Table 4. Perception of the importance of the future adoption steps.

Step	Perceived average importance
Capacitation of more professors and lecturers in BIM	Between important and very important
Inclusion of BIM concepts in other disciplines	Between important and very important
Development of further research in BIM (post-graduate level and study groups)	Between somewhat important and important

7. Conclusion

The main result of this research was the systematization of steps for BIM adoption in a university, which are summarized in Figure 2. The steps were divided in first steps (which have already happened in the adoption process in this particular institution), and in future steps. Some of the future steps are already in motion for a wider BIM adoption in the university studied.

This research was also able to associate the steps with three areas: professional capacitation for lecturers and professors, research culture and teaching strategies.

The contribution of this paper is the formalization and description of the development of the BIM culture in a university, and can possibly be used as a roadmap for other institutions that perceive the need for BIM adoption and capacitation in-campus.

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Transdisciplinary Engineering: Crossing Boundaries
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3i Engineer: An Approach Based on a Brazilian-French Collaboration

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Abstract. The globalization era is setting new challenges in several areas such as: manufacturing processes, design offices procedures, educational organizations, amongst others. In this volatile world, the importance of engineers role is becoming more evident, since they are the drivers for delivering to the market all those demanded innovations. With the advances in technology, engineering education has been requested to change. Traditional approaches are not able to fulfil the expectancies of both, the students and the market. In this scenario, Engineering Schools around the world have been developing several initiatives (e.g. CDIO, Olin College, Insper Institute), making more investments in labs and equipment, devising new ways of lecturing, promoting more interactions. Compiègne University of Technology (UTC)-France and Federal University of Technology- Parana (UTFPR)-Brazil have a strong partnership since early 1990. Considering the above context, this work discusses the scope and preliminary results of a joint initiative from both universities, named 3i Engineer. It aims at structuring a joint innovative engineering course, beyond simple students exchanges, double-degree and internships in companies abroad, based on the tripod: innovation, industry and interculturality. A preparation work was conducted at both universities. A Seminar, held at UTC-Compiègne, on February 03rd-05th, 2016, involving 15 faculty members started the process of defining a feasible framework for the aimed approach. Intercultural issues emerged as a major subject to be addressed. At the end of the seminar, three scenarios were identified. Additionally, the next stages were also discussed and planned. At the end of September 2016, it is expected to select a scenario and establish the guidelines for its implementation.

Keywords. Interculturality, globalization, innovation, engineering education

Introduction

From the middle of the 1980´s, the world has experienced profound transformations in several fields (i.e. social, technological, scientific). Economies that were closed and old fashioned technologically, were encouraged to free trade, expanding and originating many multinational companies.

Such modifications were also sensed on the way engineers were educated. By that time, most courses focused on engineering science instead of engineering practice. According to Rajala [1], industry was frustrated by the lack of professional development, despite the engineering graduates being well prepared technically.

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Thus, several working groups were set in many countries in order to envision the future for the engineering education.

The engineering 2020 Project [2], using the technique of scenario-based planning, examined four scenarios. It states that innovation will be a key issue for a nation to compete properly, with engineering being essential to this task. However, engineering field will have to be able to adapt continuously to new trends, technologies and provide means for educating the next generations of engineers.

Another example is the CDIO initiative [3], which started as a binational task-force (i.e. involving universities from Sweden and the USA), that aims to improve engineering education, based on an open-architecture, that is freely available, containing: methodologies, products and templates.

Many other works could be mentioned at this stage. However, by now, it is already possible to verify the importance and extension of the engineering education challenges and discussions.

Compiègne University of Technology (UTC)-France and Federal University of Technology-Paraná (UTFPR)-Brazil are technology-based universities. They focus on structuring and delivering engineering courses. Additionally, they have been collaborating for more than 25 years. Both universities are well informed of the fast changes in: technology, demands from industry and engineering teaching. Therefore, they are aware of the need of a step forward in terms of preparing the engineers for the future. Based on the will of collaborating and their particular characteristics both universities decide to discuss and propose an approach for tackling the new engineering education demands.

The objective of this paper is to discuss the scope and preliminary results of a joint initiative from both universities, UTC and UTFPR, named 3i Engineer, which aims at structuring a joint innovative engineering course, based on the tripod: innovation, industry and internationalization.

A working framework was discussed and set, based on literature and successful experiences from both universities. The preliminary results are encouraging and motivated the group to plan the next steps.

This paper is organized as follows. Section 1 presents the background and motivation for conducting the main work. Section 2 briefly describes the methodology adopted. The obtained results and discussions are contained in section 3. The closing remarks are presented in section 4.

1. Background and motivation

This section provides an overview on the main characteristics of both UTC and UTFPR, as well as, illustrates the how the partnership between both is developing. At the end, the envisaged challenge for the future in the aimed collaboration is described.

1.1. The Compiègne University of Technology (UTC)-France

UTC is both a French national university and an engineering school, founded in 1972, with autonomous training and pedagogy and an innovation-intensive, interdisciplinary technological research program. Nowadays, are enrolled at UTC courses: i/ 4000 students in the engineering area; ii/ 380 Master´s degree students; and iii/ 340 Ph.D. students. There are more than 21000 UTC alumni in 105 different countries. Usually, a

UTC student spends from six to 18 months abroad, including one of his two six-month full time industrial internships. UTC is reckoned for its innovative approach towards preparing engineering students. Therefore, students at UTC can personalize their study profile through a rather flexible curriculum. This degree of flexibility ensures perfect coherence between personal inclinations and ambitions. The freedom the students have to choose their courses has always been seen a factor contributing undisputed qualities in terms of their decision-taking capacity. For that, UTC is always restructuring its training schemes to comply with societal evolutions and demands from enterprises. Finally, it has to be mentioned that UTC holds an Innovation Centre, which aims to stimulate innovation whatever the format and creativity, with an international vista. It is a focal point, a locus for exchanges, creative initiatives and enables those with novel ideas to update their scientific, technological and engineering knowledge bases and to exchange on their innovations with real field constraints.

1.2. The Federal University of Technology-Paraná (UTFPR)-Brazil

The Federal University of Technology – Paraná (UTFPR) is a public institution, owned by the federal government, with 13 campi located in the south of Brazil. The institution has its origin as an Elementary School for Craftsmen, founded in 1909, and has gone through changes until it officially became a University of Technology in 2005.

UTFPR campi are spread throughout the State of Paraná offering over 117 undergraduate courses, 36 graduate programs (six doctorate and 30 masters programs) as well as an expressive number of research groups. Nowadays, UTFPR has University has around 2.300 lecturers (professors, senior lecturers, readers), 1.000 administrative staff and around 30.000 students. The courses offered concentrate on the engineering areas: Mechanical, Civil Construction, Electronics, Computer Science, Food, Textile among others.

UTFPR is the only University of Technology in Brazil and the largest one offering Engineering Programs. Additionally, it has strong ties with the industrial sectors in several fields of the Brazilian economy. In addition, since late 90´s UTFPR provides support for spreading the entrepreneurial culture, via its Innovation Agency.

1.3. The collaboration between UTC and UTFPR

The collaboration between UTC and UTFPR started in the early 1990´s. Since then, students from UTFPR and other Brazilian universities normally spend one year at UTC. During this period, they participate to an intensive French course, study for one semester at UTC and then go through a six-month industrial internship. Up to now, more than 1.000 Brazilian students came to UTC. Also, every year, about twenty students from UTC are going to Brazil for one semester of study and in some cases for industrial internships. Since several years, UTC and UTFPR have joint double-diploma programs, which are followed by a small number of French and Brazilian students. From the beginning of the 1990's and up to now, a substantial number of students and faculty staff from Paraná came to UTC to do their doctoral studies. According to Schaegger [4], at that time, the Brazilian students would go to UTC to attend few courses and pursue an internship in a company located in France. Usually, their knowledge of French was very basic. Nowadays, the collaboration has changed with the students mastering better the language and the strengthening of research initiatives (e.g. M.Sc. and Ph.D. students exchanging).

As pointed by Schoefs [4], the new dynamics of the double diploma in several courses involving both institutions is a positive indicator that the partnership is functioning well. Also, the synergy with industry, allows the students to conduct their final year project with focus on real cases, either in France or in Brazil.

The students from both countries state they have benefited from either the exchange program or double-diploma. Two french students declare they present a differential from being proficient apart from French, in Portuguese and English. On the other hand, the Brazilian students mention their employability has increased, mainly amongst French companies based in Brazil.

Therefore, it is possible to identify the strength of the partnership between UTC and UTFPR.

1.4. The challenge

On October 2nd 2015, a Strategic Meeting was held between UTC and UTFPR, in Curitiba, in the presence of UTC President, Pr. Alain Storck. In the context of fast and major alterations of global economies, engineering education is going to face the rethinking of its role, pursuing the aim of preparing professionals capable of adapting themselves to an even more complex and heterogeneous environment.

At the end of this strategic meeting, it was therefore agreed to work on the design of a joint innovative engineering course, emphasizing on innovation, industry and internationalization, which go beyond students and staff exchange, having courses with double-degrees, internship in companies abroad, amongst others.

2. Methodological approach

The methodology, similar as that adopted by [5] and [6], is as follows:

1. Setup of working groups on both, UTC and UTFPR;
2. Literature review, aiming to define the state of art for engineering education over the next 20 years (from (2015);
3. Regular meetings, via Videoconference involving UTC and UTFPR group members, focusing on key subjects identified;
4. Seminar at UTC (3-6 February of 2016);
5. Preliminary findings as a result of the February seminar;
6. Two videoconferences (May to August of 2016);
7. Final seminar end of September,
8. Conclusions (economic feasibility and timetable).

3. Results and discussions

3.1. Working groups

After the Strategic Meeting, working groups were set in both universities. These groups were composed of six faculty members having experiences in educational, industrial and international affairs. A cloud driver (i.e. google drive) was set to upload de materials of interest (e.g. papers, cases, videos).

3.2. Literature background

The literature review has shown that there are several initiatives around the world discussing the challenges for engineering education. This section briefly describes the main works consulted to support the envisaged approach.

Basic works

On a broader sense, the report produced by Ernst and Young [7] indicates it its study for the Australian context, that there are five driving vectors of a change in the education sector, which are: i/.contestability of markets and funding; ii/ democratization of knowledge and access; iii/ digital technologies; iv/ integration with industry; and v/ global mobility.

The work found in [8] broadly discusses the future of the university. It is stated that the model of funding universities must change, to be feasible on the long term. In addition, it is perceived that courses should be structured for a group of globally mobile students.

On the field of engineering, King [9] discusses a set of issues concerning the capacity and robustness of the Australian education system to graduate enough engineers that will be required for the future.

UNESCO sponsored a fundamental work on the influences on the field of engineering [10]. The report identifies and explores issues, challenges and opportunities for engineering around the world. It brings to discussion the need to reinforce the role of engineering as the driver of innovation, social and economic development. For that, it is noticed the need to change engineering education, curricula and teaching methods, focusing on a problem-solving approach.

Spencer and Mehler [11] advocate that education is the pathway to support the challenges engineering is facing, mainly with the development of new methods of teaching and learning, reinforcing the students should understand the importance of working in groups, collaborating and improving their interpersonal relationships.

The report from the National Academy of Engineering [2] mentions that by 2020 engineers will be working with teams of engineers from different countries, as well as, non engineers, to provide solutions for yet unknown problems. Furthermore, these graduates will deal with large-scale systems, when they will be asked to use better judgement and critical thinking.

The CBI report [12] emphasizes that science, technology, engineering and maths (STEM) skills are the cornerstone for the future of a knowledge-intensive economy. Additionally, it discusses the low participation of woman in the STEM arena.

Engineering education initiatives

There are initiatives for tackling the engineering education challenges already implemented in several places and at different maturity levels.

The Conceive-Design-Implement-Operate (CDIO) [3] approach, aims at educating graduates on fundamentals of engineering knowledge, so they can develop and operate complex systems. The CDIO initiative provides a complete framework, syllabus [13] and standards for its implementation. Nowadays, there are 118 members around the world utilizing CDIO materials [14]. Additionally, this survey indicates that participant universities are improving their students' personal and interpersonal skills, as well as, the overall knowledge over complex systems. A project involving Chinese software engineering students and IT engineers from Japanese companies, using a CDIO approach is described in [15]. They identified the students improved their managerial and soft skills.

Olin College of Engineering was founded in 1997, seeking to innovate in engineering education [16]. Much of Olin College's curriculum is built around hands-on engineering and design projects. In this way, they expect the graduates to be leaders in solving the pressing global challenges of today [17], [18]. Olin College offers degrees in electrical and computer engineering, mechanical engineering and engineering.

On the Brazilian context, the Insper Institute [19], launched in 2015, courses on: mechanical engineering, mechatronics and computing engineering, based on the Olin College approach. Its main aim is to prepare engineers to innovate, develop products and business.

Other initiatives could be mentioned. However, these are representative and fulfil the scope of the present study.

Innovation

Innovation is widely portrayed as a key element to ensure successful competition in a worldwide economic context [6].

ASEE [20] brings to light the question on how an appropriate environment can be assembled, so engineering educational innovations can occur with desired frequency and support the education of future engineers. One of its main recommendations is to encourage entrepreneurship and competitions, so engineering students can deal with business formation and finance, intellectual property, amongst others.

The work produced by [5] aimed at understanding which elements guide the engineers way of thinking. After a field survey, the authors identified six terms that form the core of what they coined as Engineering Habits of Mind (EHoM): i/ systems thinking; ii/ problem-finding; iii/ visualising; iv/ improving; v/ problemsolving; vi/ adapting. Their main conclusion are that changes in engineering teaching should be implemented, so engineering careers could be more effectively presented to young people.

The role of entrepreneurship in engineering education is discussed by Byers et al. [21]. The authors reinforce the importance of engineering educators, who besides preparing the students with technical and analytical expertise, provide insights on how to be resilient, creative, flexible, so they can become more innovative and entrepreneurial.

Internationalization

The issue of internationalization is widely and deeply discussed in [22]. However, some particular works must be examined.

The British Council conducted a survey [23], to support the UK Strategy for Outward Mobility. Its main findings include that the motivation for the students to go abroad on a mobility program were a desire for enjoyable and interesting experiences, to broaden horizons, and to enhance employability and career prospects. Additionally, the students reported to be interesting to develop intercultural awareness, independence and self-confidence. On the other hand, in order to go abroad the availability of funding emerged first, as well as, personal safety and security, reputation or perceived quality of host and location and language requirements.

Jones [24] brings into context the employability skills (i.e. flexibility, organization, negotiation and good communication) and how education abroad can develop them. According to him, the international experience as student or volunteer can enhance the transformational learning. Additionally, he introduces the idea of creative intercultural opportunities derived from internationalization for enhancing local curriculum.

Industry

Stephens [25] states that industry, society and engineering schools should collaborate, so a sufficient number of qualified engineers can fulfil the demands from industry and market. In addition, it is emphasized the importance of students mastering soft skills (e.g. work in teams, communicate, defining problems). Two measures recommended to close the gap with industry on the demanded professionals are: i/ first and second year engineering student project; and ii/ internships.

The Brazilian National Confederation for Industry produced a report [26], which argues that a major shift in the Brazilian engineering education is fundamental for the improvement in productivity and economy performance. It highlights the importance on devising means for stimulating the cooperation between university and industry, amongst other findings.

The enhancement of opportunities to develop work-related learning and employability leverages the learning of the subject being studied, argument [27]. Furthermore, this approach induces resilience and expose students to unfamiliar situations, helping them to deal with anxiety.

Lessons learned for UTC-UTFPR

From the work conducted until this moment, the following points drew attention: i/ the pace in which technological and economic changes in the world are occurring is increasingly high; ii/ engineering plays a fundamental role in matching the market needs in a complex world; iii/ there is a distance between engineering graduates and the industry demands for professionals; iv/ this requires a redesign of engineering courses; v/ international cooperation is essential for the academic environment; vi/ innovative education tools have to be developed.

3.3. Meetings: UTC-UTFPR

From these assumptions, the groups held a set of videoconference meetings in late 2015 and early 2016. The framework for further discussion was structured and a consensus was reached.

Why 3i

From the papers examined, discussions held and profiles from both universities (infrastructure and faculty staff), the synergy between innovation, internationalization and industry (therefore, the "3i" label) was observed.

UTC is known for the quality of its engineering courses, as well as, it focus on internationalization, partnership with industry, technological research and innovation. In 2014, the Centre of Innovation Daniel Thomas was opened.

On the other hand, UTFPR has strong ties with industry and its Innovation Agency offers support for the academic community.

Additionally, the cooperation between both universities on the internationalization arena is well established and can be considered mature.

Thus, both parties decided the 3i would be the starting point for suggesting novel approaches for extending the collaboration already implemented.

The intercultural issue

On a peer-to-peer discussion, it emerged from the UTC faculty staff, that on the branch of internationalization, the interculturality issues were very influential and should be examined in more detail. For that, a conference of Dr. Pateau from UTC [28] provided the basic concepts for better understanding the importance of considering interculturality in the scope of an engineering course.

Thus, interculturality refers to the interaction of people from different cultures and backgrounds. Besides, sometimes, natural difficulties concerning different languages and cultures, involves various ways of thinking, particular social rules, specific laws, amongst others. When there are significant differences between the cultures of two groups, interculturality should be addressed carefully.

On the other hand, it has been observed that the merging of different cultures induces social enrichment, fuels creativity and provides competitive advantage (i.e. via better communication and negotiation).

Therefore, it was decided that interculturality should be examined in more detail in the next stages.

3.4. The Seminar at UTC: issues and main results

UTC was commissioned to organize a joint seminar, on February 3rd – 5th, 2016, in Compiègne. The Brazilian group involved four faculty staff from UTFPR and one representative from the Paraná State Government. The UTC group was composed of ten faculty staff. Dr. Hughes Choplin was appointed as moderator and was responsible for guiding the work.

At the beginning, each participant was asked to report a referential intercultural situation. These were categorized in interpersonal and organizational issues.

Jacques Pateau Conference

To grasp a deeper understanding on the interculturality theme, Dr. Pateau gave a talk to the group with the title: Interculturel: Situations et Compétences. He reinforced the need to pay attention to virtual closeness, how to construct bridges over two cultures, the increasing demands for cooperation and the subtleties of the decision process, amongst others.

Working groups

Next, the participants were merged and split into small groups. The first task was to produce and describe in details two different referential situation focusing on interculturality. After the discussion, the moderator identified the following main points: the demands for adaptability and flexibility, the integration of intercultural issues on the management of an international project (life, work), the ability to communicate in other languages (apart from English) and to identify codes and the mastering of different IT resources. Following, another compostion of small groups was asked to formulate three suggestions on how intecultural issues could be addressed in a framework of development for five years.

Additonally, aiming at understanding the industry perspective over engineering education, Mr. Allan Tissier, Director of Automotive Plant in Curitiba-Brazil, gave a videoconference talk to the group. Also, three senior engineers working for a Truck Manufacturing Plant, Brazil, recorded on a video, their impressions over the engineers profile that Brazilian universities are delivering.

Main results

From the overall discussions, three possible scenarios were drawn to couple the issues discussed during the seminar.

SCENARIO I-Label. To create a 3i Certificate, that would be delivered to students who have followed a demanding package of courses and projects linked to 3i. *Pros*: i/ it is easy to implement in practice; ii/ the students and lectures can realise that it is a suitable and interesting approach. *Cons*: i/ the scenario can be seen as a strategy similar to what is already in course.

SCENARIO II-International Vocational Course. Vocational six-year programs where the students will spend fifty per cent of the last years in industry: two years in the country of origin of the students and two years in the country of the sister university (UTC or UTFPR). *Pros*: i/ strong emphasis on industrial practice; ii/ intercultural experience. *Cons*: i/ funding; ii/ a six years time span.

SCENARIO III-Novel Course. The idea is to structure a complete new engineering course oriented to 3i. A group of students will alternate between both countries. Common courses for groups of students of UTFPR and UTC can be performed in presencial or distancial form. The pedagogic approach should be coupled, with contents co-definition and joint projects co-developed. *Pros*: i/ 3i focused course structure; ii/ both universities involvment from the beginning. *Cons*: i/ funding; ii/ intercultural issues for contents definition.

UTFPR and UTC are aware that, independently of the scenario chosen, they must comply with regulations (either from university or from government). Additionally, the accreditation bodies shall be involved in the discussions.

3.5. The next steps

Apart from meetings via videoconference and exchanging further information, UTFPR will host a meeting, with the participation of UTC faculty staff. The three scenarios will be re-examined. This time, it is expected to discuss in more detail the influences of innovation and industry contexts in the envisaged structure of collaboration between both universities.

4. Closing remarks

In the 21st century the world is changing rapidly. Engineering as a profession and engineering courses must reinvent themselves to cope with these novel demands.

UTC and UTFPR have developed over the years a strong partnership. Both universities are aware that they have to move further in the way they collaborate. Innovation, industry and internationalization (interculturality) can form the core of a novel framework of cooperation between both universities.

The three scenarios deployed in this work have to be further discussed and matured. It is already a consensus that whichever is the path chosen, its implementation should occur as a pilot approach, to better understand its implications in practice.

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Part 7

Collaborative Design and Engineering

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Transdisciplinary Engineering: Crossing Boundaries
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How to Enhance Customer Experience in Retail: Investigations Through a Case Study

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Abstract. In the last years Customer Experience (CX) has become a novel approach to obtain a competitive advantage for numerous companies. The complexity of interactions among the customer, the physical environment, the company's employees, the product and/or related services requires transdisciplinary methods and tools from marketing, engineering, human resources and culture, technology, organization, management and phycology. The present papers aims to provide an overview of what Customer Experience is, how it can be used to design the meaningful touchpoints between the customer and the company and propose a CX-oriented strategy to design them in stores. Some interesting insights are discussed thanks to experiments performed in a real test case.

Keywords. Customer experience, Touchpoints, Retail channels, Journey Mapping

Introduction

In the recent years, the creation of an enjoyable shopping experience has become one of the factors to effectively help enterprises in competing in the arena of retail. Several authors carried out researches to demonstrate that consumers who enjoy the shopping experience buy more goods than those who do not, are more satisfied and reveal a repeat-purchase behaviour (loyalty).

Customer experience (CX) plays an important role in customer satisfaction and loyalty attitude. They are linked to the fun provided in the store by adding attractive areas such as bars, gyms and games, to the emotions created by the enjoyable elements at the point of sale and to the benefits achieved by customers. The identification of which strategies are more successful for a specific retail passes through the understanding of the customer journey and hence of his/her expectations. There are a variety of techniques for analysing the journey as video ethnography, mapping process, touch point analysis and the understanding of all activities and constraints. As well as there are a variety of techniques to design proper CX elements to change the journey and hence the customer behvaiour.

In this context the present research proposes a structured approach to map the journey and design CX. It is then illustrated by a case study in fashion retail where an

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enjoyable experience on the touchpoint after payment is designed and prototyped to make the shopping activity more attractive and funny.

Customer journey mapping allowed the research to identify who are the main target customers, to depict a set of representative personas, to understand their expectations and wishes, to formulate a problem and find proper strategies to improve their experience at the final touch point. For instance, the analysis actually highlighted that after the payment process clients generally take the way out without any happiness and the last record is only the payment activities. The actual approach has been changed by giving a "GLUE" (Giving little unexpected extra). It consists of a game that makes the contest funny and recordable. It is a really out of context object positioned on the desk after the cash register area.

The effectiveness of the game prototype and the success of the adopted approach are proved thanks to the collection of customer answers. Interviews were submitted to more than 1000 customers with a fidelity card in order to verify the success of the adopted approach. A report elaborating the collected results was created to share the customer experience approach across the company departments. Most customers found the game funny; it generated an increased income of cross selling and about 30% of persons decide to ask for a fidelity card to play with it.

1. Customer Experience and the role of touchpoints along the Journey

Retail is a market where an extensive range of products and commodities are made available to customers. It has been demonstrated that one of the meaningful levers of customers' decision-making to purchase, involvement and motivation is the quality of the marketing experience and its ability to stimulate the emotional and experiential parts [1]. This phenomenon finds out maximum fertility in retail (e.g. fashion, furniture and household products) where creativity, style, individuality, and more generally the personality of each user influence customers' decision-making [2]. In the last years what is happening in retail is a focus shift from product and service design to "customer shopping experience" design and to the definition of all clues that people detect in their shopping process and that make it satisfactory [3]. This does not mean a lack in product/product-related-service performance and perceived quality but an increasing orientation to enhance the experience they provide in the physical and/or digital shopping environment.

The Customer Shopping Experience aim is actually to give to the consumer an opportunity, an emotion or a special memory of the shopping in order to build loyalty, improve motivation of purchuase and manage the relationships with the customer [4]. That leads to consider retail not only as a market where products and fashion collections are shown to be bought but mainly a space where events happen. The possibile events are for instance the opportunity to have a personal shopper to reivent the customer's image, to enjoy happy hours and shows, to attend to the presentation of a new book by its author. The shop can become a DJ set. In all cases, the goal is to ensure that consumers realize a special experience in the store that has to leave an emotional moment and memory [5].

The design of experiential services and hence of elements stimulating customer emotions, creating a dinstinctive experience and fun at shops, is an emergent scientific area and a challenge for many organizations [6].

CX is the internal and subjective response that customers have to any direct or indirect contact with a company. Direct contact generally occurs in the course of puchase, use and service while indirect contact often involves unplanned encounters with representatives of a company's products, service or brands and takes the form of word-of-mouth recommendations or advertising [7]. In addition, CX's construct is holistic in nature and involves the customers' cognitive, affective, emotional, social and physical responses to the retailer [1].

CX is co-created through the multiple customer interactions with the several shopping experience elements or clues set along his/her journey [3]. These elements are the context within which an experience takes place and, are generally called touchpoints. Their identification is not a trivial task because they depend on the specific business that has different overviews and prospective interactions with the customer [8], are in pre- and post-purchase [9] and occur through different retail channels [10]. However, if the company is able to detect the touchpoints and design the clues to improve CX, it will be able to introduce the right journey's elements to influence the customer to choose/repurchuase the products and/or service it offers.

Customer experience studies exploit the journey mapping technique to identify all touchpoint episodes encountered during the service delivery process [11] and subsequently analyse the customer response to the introduced elements in terms of satisfaction, fun, boredom and frustration. The customer journey means the customer's transition from never-a-customer to always-a-customer as defined by Christopher et all. [7]. It is a visual draw of the CX that describes where the customer could be in contact with company directly or indirectly showing the different touchpoints characterizing this interaction. The customer journey maps can be used to represent the mental user models (ie. empathy map), the flow of interactions and all possible touchpoints between the company and the customer. Their analyis are very useful for companies to set strategies to take the customer from awareness to loyalty.

If we would make an example customer journey could be compared to a bus trip from the central bus station to city center. We could have many busses that leave the central bus station and any person choose is own trip considering the travel he/she wants to make. During this trip you have different views and many stops where you can get off but the aim of any company is to bring you to the city center and let you enjoy the trip in order to consider to do it again and/or suggest it to somebodyelse.

Numerous studies confirm that satisfaying customer responses can be achieved on using cues, stimuli and service encounters [12-15] at the touchpoints of the his/her subjective journey [6; 16]. Different techniques, both qualitative and quantitative, are proposed in literature to draw customer journey maps [17] and measure the quality of CX as follows: direct interviews, surveys based on data collected from web resources, role-playing, ethnographic research and analysis, etc. [18]. However most researches in this field stops at the definition of the emotional curve superimposed to the detected map. They do not usually propose a structured method to support designers and marketing analysts in the identification of use scenarios, interactions at touchpoints, customer satisfaction evaluation and design of touchpoints to improve CX.

Literature overview points out some critical issues to be faced in CX field as follows: 1) a scarcity of systematic research on CX Management and calls for a theory-based conceptual framework; 2) a lack of CX-oriented methodologies to coherenty introduce CX in product design, service offerings, company's organization, 3) the necessity to move beyond the elements under the retailer's control (e.g. store atmosphere, music, lightings, price and assortments) to a broader undestanding of the multiple factors affecting CX; and finally 4) an inadeguacy of reports of real experiences in retail.

2. How to improve CX: the proposed approach

The proposed approach to tangibly improve CX in retail consists of five steps. Each step supports the designer respectively in analyzing the customer journey, identifying the main drawbacks and opportunities/strategies to improve the experience, designing successufull touchpoints, prototyping solutions to make the shopping activity more funny and test sample customers' responses. The approach is defined for the retail sector and in particolar to improve the shopping experience. For that reason, it does not consider any other direct or indirect contacts between the company and the customer except for those occurring in stores. They are as follows:

STEP 1: Analysis of customers in retail stores through the direct observation of people interacting with products and personnels in a specific atmosphere and enjoying the shop services (e.g. Wi-fi connection, dressmakers, personal shopper). The ethonographic analyis is also supported by Video Interaction Analysis technique (VIA).

STEP 2: Representation of the Customer Journey Map to identify the main digital and physical touchpoints in the store. It is in the form of a curve in a 2D cartesian space where the x-axis reports the episodes of the journey and the y-axis the achieved level of loyalty. IDEF 0 and 3 techniques can be used to better define and then decompose the interactions, input/output flows, main actors and process constraints [19].

STEP 3: Identification of critical events by creating an emotional curve to represent the level of customers' satisfaction and to recognize which touchpoints need to be redesigned. Two tools can be used to carry out this step: structured or semi-structured (e.g. conversational approach) interviews and the application of the ZMET technique according to Zaltman [20]. At this stage, the designer has to list all possible strategies for improving customer satisfaction such as gamification [21], and select the best one to overcome main limitations. The result of STEP 3 is the definition of the touchpoint requirements to apply the CX strategy.

STEP 4: Design of touchpoints and prototyping of solutions implementing the identified strategy. The design can regard some elements of CX, specific clues and product-related services to improve the contact.

STEP 5: Experimentation of the prototyped solution in real retail stores and measurement of customers' satisfaction by 1) ethnographic research (e.g. direct observation by experts) and/or 2) submission of structured or semi-structured interviews and/or 3) the application of the ZMET technique. The experimentation is followed by the elaboration of collected data by representing the feedbacks in a new emotional curve and by the definition of guidelines to improve CX.

3. The case study in fashion retail: an investigation

3.1. The applicative context

The proposed CX-oriented approach had been preliminary applied in fashion retail. The industrial partner of this research is an Italian large-sized company, producing shoes, bags, clothes, fashion accessories, etc. for three three major brands with almost 500 stores Worldwide. It produces goods both for male and female, children and adult. It is positioned in the low-cost market sector. Its main competitors are brands such as H&M, Zara, Bershka and Uniqlo. The company brand where the experiment took place is the one oriented to youngers and it proposes cheaper fashion goods than others.

3.2. The map of the customer journey in retail

The map of the customer journey is the result of two parallel studies: one conducted in collaboration with the industrial partner and one based on the ethnographic analysis of real customers into the retail stores.

A set of interviews was submitted to the company's marketing, design and sales departments. The elaboration of the collected answers led to the definition of the solutions in terms of ways to be in contact with the customer adopted by the company to achieve the maximum level of loyalty. Results are represented in the graph of Fig.1 that correlates possible phisical and digital touchpoints with the achieved confidence level in the current company / customer relationship. The graph shows that the highest level of loyalty, demonstrated by the ownwership of the fidelity card and to the availability of customer personal data such as telephone number and email, is reached at the stage of purchasing both in the website and in stores. This result pushes the analysis to focus on the shopping experience in stores.

The second study took place in eight sample stores, located four in the centre, two in the north and two in the south of Italy. All have more than 1000 square meters of surface. Their layout is arranged into three sections as follows: Men, Women and Kids. They provide a free wifi service. Moreover inside the store there is a radio system with dancing music and an ambient profume. In all stores the observation of customers' behaviour was repeated thrice within a day's time: in the morning (from 10:00 to 11:00), at lunch break (from 13:00 to 14:30) and finally in the late afternoon when there is the maximum crowd (from 18:00 to 19:00). Videos were recorded and then elaborated to create an IDEF0 model of the purchasing process till the 2nd level of activities' decomposition. It allows the analyists to identify the main episodes of the customer journey in the shops (reported in the columns in Figure 1).

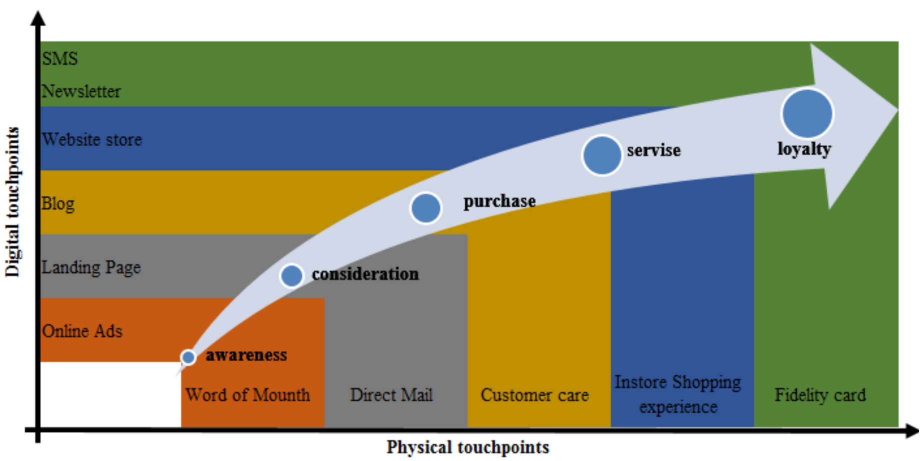

Figure 1. Correlation between physical and digital touchpoints and the measured loyalty curve.

20 customers for each store were selected and conversational interviews were submitted to investigate the degree of satisfaction at the different physical touchpoints. In addition two experts observed customers to uncover the deeper motives of customers, the emotional peak and end moments within the Customer Journey. At this stage the ZMET technique was not applied becaouse the study was only preliminary. This analysis lead to the creation of the emotional curve reported in Figure 2. In it evident that the final touchpoint is the most critical episode in terms of customer satisfaction. Most interviewed persons actually declared to be annoyed. The last experience they had is actually payment. However, it leaves a footprint and a memory of the shopping experience crucial for the loyalty. Therefore this experience must be changed by introducing a disruptive initiative that completely modify the customer emotional state.

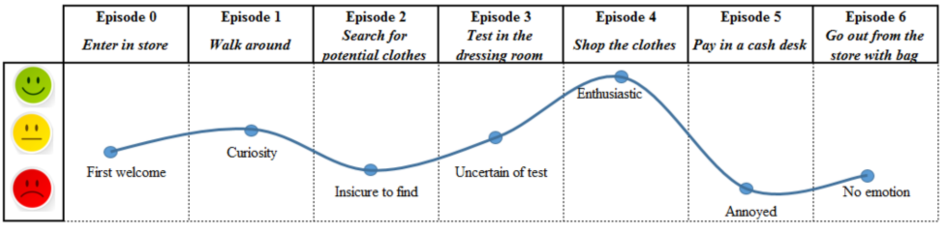

Figure 2. The emotional curve mapped in the customer journey in fashion stores.

The result of STEPs 1-3 is a list of requirements as a roadmap for CX element design as follows:

- to introduce a disruptive and impressive CX element at the final touchpoint and to create an extremely positive emotion in order to drive loyalty;
- to create a novelty effect;
- to leave a memory of the shopping experience and give something to remember it in order to motivate to come back again, to recommend the brand to friends, to defocus the attention from payment;
- to engage the customer by adding a gamified system at payment;
- to stimulte positive perceptions by involving multiple sensory channels;
- to use funny colors and taking up an area comparable to the cash dimension;
- to make use of familiar images and playful objects.

3.3. The design and prototyping of the final touchpoint

The above-mentioned requirements were framed in the following design problem: Creation of an attraction (what?) at the final touchpoint (where?) by proposing a challenging game (how?) to engage loyal customers (to whom?) in order to create a memory inducing repurchasing and spreading the word to friends (why?).

The solving design concept regarded to create a game at the final touchpoint that allowed customers to play and in case of reward to receive a gift. This strategy implemented the three main parts of gamification that are the motivational affordance, the resulting psychological outcome and the further behavioural outcome as reported in [22]. Figure 3 sums up how the customer journey was reconfigured by breaking the payment experience. Actually, after the payment the customer equipped with the fidelity card could fish one ball and get the prize associated with the extracted colour. Two of the four prizes allowed the customer to achieve an extra online bonus that gives the way of the cross selling and bring him/her to an “omnichannel” experience.

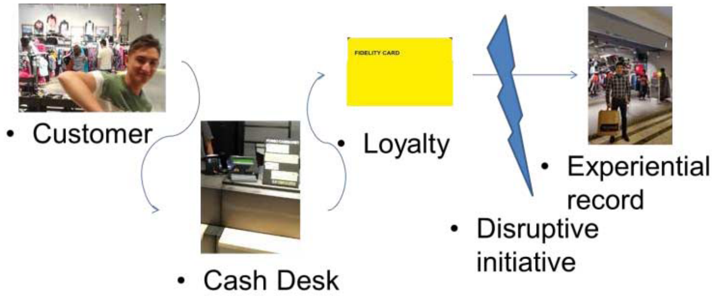

Figure 3. The model of the introduced customer journey at the final touchpoint.

The concept was then embodied into a sort of "fishing box" that represents a challenge in the current stores of the brand (Figure 3). The box was made of a printed plastic coated cardboard material containing 16-18 coloured balls. It was shaped as a section of pyramid that remembers a pop-corn box like that in movie theatre. It was closed by a cover with a hole in the center whose diameter was large enough to allow a hand to enter and move in the box. The selected colors were yellow, blue and fuchsia, chosen because they are strong, impressive and funny. The box was 40 cm high and positioned on the desk. Position and dimensions were chosen to avoid customers to look inside the box while fishing the balls. The total cost for one box was of 40 Euro.

Figure 4. The fishing box prototype.

The dynamic of the game is as follows: once the loyal customer has paid at the checkout he/she is invited to fish in the box, called "POP BOX", where there are 16-18 balls with 4 different colors. A different scenario is linked to each color (i.e. Green ⇒ Lollipop; Yellow ⇒ online discount; Blue ⇒ online discount; Red ⇒ you did not win). Before playing, the customer is informed about the game and the procedure to follow by the shop assistant. While playing, he/she can watch all possible prizes in a display with a music that creates suspence.

3.4. Investigation of the solution success by interviews

Semi-structured interviews are coupled with ethnographic research conducted by two experts in Human Studies and Marketing to explore the (unconscious) needs, wishes, associations and motives of customers in case of playing with the Pop-Box.

The Pop-Box prototype was installed into two stores. Investigations were carried out in two different periods both lasted 1 month: one of great turn-out and one with a lower number of visitors. Each period lasted two weeks. In Period 1, the Box is fulfilled with 9 red balls(you did not win), 3 green balls (online discount), 3 blue balls (online discount), 3 yellow balls (lollipop). In Period 2 the Box is fulfilled with 1 POPBOX with balls: 3 red balls(you did not win), 3 green balls (online discount), 3 blue balls (online discount), 3 yellow balls (lollipop). Differences of balls' colors in the two periods depend on the fact that the analysts would test if the re-purchuase percentage was linked to the chance of failure. The probability to failure is higher in period 1 that in period 2. So, the analysts expected that customers would come back to the shop and play again till they would win. This not happened.

The Box was positioned at the end of the cash desk and a shop assistant informed customers about the aim and the procedure of the game and she/she invited him/her to fish a ball. Moreover, the assistant specified that the game was dedicated only to customers with a fidelity card.

Respectivelty for each period, Table 1 and 2 report the number of customers that played the game, the number of new fidelity cards that were subscribed to enjoy the game and the registered emotional state.

Table 1. Results from Store 1.

	Tickets	**Tickets made with loyalty card**	**loyal customers fishing balls**	**N. of enrolled customers thanks to the game**	**% satisfied people**	**% indifferent people**	**% disappointed people**
Period 1	3379	654	251	25	76	12	12
Period 2	2052	258	227	13	72	20	8
Tot	5431	912	478	261	74% *(Average)*	16% *(Average)*	10% *(Average)*

Table 2. Results from Store 2.

Store 2	**Tickets**	**Tickets made with loyalty card**	**loyal customers fishing balls**	**N. of enrolled customers thanks to the game**	**% satisfied people**	**% indifferent people**	**% disappointed people**
Period 1	1987	932	257	17	82	11	7
Period 2	1491	628	66	11	72	25	3
Tot	3478	1560	323	38	77 % *(Average)*	18% *(Average)*	5% *(Average)*

The emotional sensation is the result of the elaboration of experimental data retrieved from the answers to direct interviews submitted to customers by the shop assistant, the pictures of customers' face expression taken after the game (Fig. 4) and finally the registered number of people that enrolled to the loyalty program to play the game. Pictures were useful to experts to elicit the unconscius feedback to the game.

The scope of this investigation is to understand the emotion of the client in the last touchpoint and how much the client is engaged in the gamification to remember his/her experience in the store. The introduction of the Pop-Box increases the number of the episodes characterizing the last part of the Customer Journey in the stores. Figure 5 reports the emotional curve deriving from the elaboration of the submitted interviews to loyal customers and the analyis of pictures taken by experts after playing the game (Figure 5). It reveals an increase of positive sensations such as curiosity and happiness connected respectively to the possibility to game and to win a prize.

Figure 5. The fishing box prototype positioned near the cash.

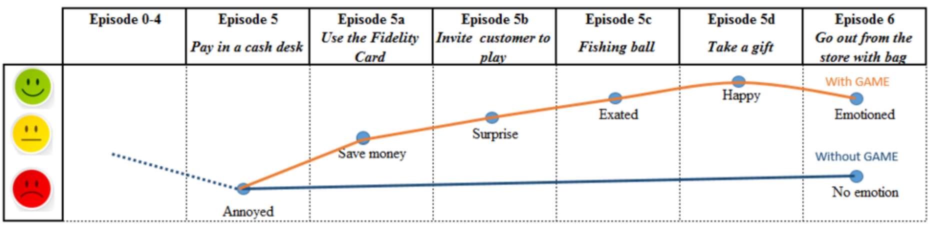

Figure 6. The emotional curve after the introduction of the Pop-Box.

From the analyis of the interviews, pictures and number of new fidelity cards it is worth to notice that 1) the game is very suitable for kids and less for mature people; 2) children are involved with the game and its colorful graphics to the extend to push their parents to subscribe a fidelity cards and to play with them the game; 3) customers appreciate more the gift in store and less the traditional online coupons; 4) the last episode of the journey transform the emotional state from “annoyed” to “happy”.

4. Conclusion

The research describes a structured method to design the touchpoints in stores based on a Customer Experience-oriented approach. It allows the customer journey to be mapped and strategies to realize an enjoyable experience to be applied. The final aim of the method application is to make the customer more loyal, create a positive memory of the experience and push the customer to repeat the purchase. Although the investigations are only preliminary and they give just some insights about the success of the approach application, it contributes to the current state-of-art in design methods as it introduces a customer experience point of view to traditional participatory design. It merges two disciplines that are marketing and design. Moreover the experiemtnal results can be useful for retailers who wants to improve the CX in their stores.

Future research will focus on the application of the ZMET techniques to better elicit unconscious customer sensations and on the collection of more case studies in this field to validate the proposed approach.

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Application of Design Thinking Towards a PSS Concept Definition: A Case Study

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Abstract. Product-service systems (PSS) have been seen in literature as a new solution towards sustainable competitive advantage. Many companies have been migrating to this novel business model, which looks forward fulfilling the customers needs and desires. One approach that could be useful to support the generation of ideas and concepts for those offers is design thinking (DT), a human-centered design approach that has been used to stimulate innovation on several business processes, including the development process. Although some authors in literature have shown what the results of using this approach to generate concepts and ideas may be, there is sparse investigation on the application of DT regarding the generation of a PSS offer. This work aims to identify some particularities and insights about the DT application in the generation of new concepts as part of a methodology for transforming a product-oriented company into a PSS provider. The DT process was performed through workshops in a participatory case study in a mid-size Brazilian dental and hospital equipment manufacturer. The DT approach was in synergy with a method to define new business models. The main findings were: the synergic application of both methods that allowed the creation of a human-centered business model; the improvement of the existing product architecture and features to support the value proposition; and a roadmap of the future developments for PSS implementation. This work presents insights to manufacturing companies that intend to add value to their traditional offerings.

Keywords. Design thinking; Case study; Product-Service System; Servitization.

1. Introduction

Product-service systems (PSS) are integrated solutions composed by a combination of products and services that aim to properly fulfill the customers' needs, shifting the competitive advantage from low-priced products to enhanced functionality [1-3]. The value provided by a PSS offer may be assessed by four dimensions: functional, physical, economic, and environmental [4]. This work focuses on the functional dimension, which is related to how the offer effectively fits customers' needs.

The proper development of a PSS depends on the thorough integration of service and product development [4-6]. However, a dominant trend of PSS development is servitization, which covers the development of services to complement already commercialized core products in order to add value to those offers [7]. The shift of product-based business models to PSS requires changes towards a service-oriented mindset. Besides, the functional dimension of the value of a PSS implicitly brings the

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concept that a PSS offer must be focused on the customers, considering their final experience. It requires a further change towards a human-centered mindset. This mindset change is even more critical in the servitization process, since manufacturers traditionally have a product-based mindset that may be tough to replace. This shift may begin by introducing human-centered design methods in the development process.

There are many publications presenting single human-centered design methods and evaluation tools that might support the PSS development, but they are rarely related to guidelines on how to apply them [8]. For requirements elucidation, for example, it is possible to find recent work proposing new isolated methods [9] and new methodologies based on existing methods [10]. Some authors in literature also propose that a potential approach for supporting PSS development is design thinking [11-13]. Design thinking (DT) is a human-centered design approach composed by particular mindsets and interrelated methods. This approach has been used by many leader enterprises, such as IBM, SAP, Samsung, among others, in order to enhance experience-based innovation. However, little investigation about DT as an approach for supporting PSS development has been done. De Lille, Abbing and Kleinsmann [11], for example, investigate how design consultants use DT to support enterprises on implementing PSS by identifying what are the difficulties, the necessary skills, their roles, and the typical characteristics of the process of changing the organization. Henze, Mulder and Stappers [12] review three retrospective case studies in order to propose an initial framework for conceptualizing how the collaborators' network should be structured for developing a PSS based on the DT approach. Finally, West and Di Nardo [13] identify the need of adapting one given DT approach to the PSS context based on two case studies, combining this approach with service design techniques.

Besides enhancing a mindset change towards a human-centered development, the DT approach may deal with some problems related to the PSS maturation. Exner et al. [14] attribute the slow spread of PSS in worldwide enterprises to the lack of validation methods, such as prototyping, on the PSS development process models in literature. The DT approach may support the solution of this problem, since it brings low-resolution prototyping and other modeling tools for validation purposes. However, it is important to understand how it should be performed in this context and what are the possibilities for coupling the DT approach into the PSS development process.

The authors of this work aim to explore how the value proposition and concept generation process of PSS may be supported by the DT approach in the servitization process. Thus, this work presents a participatory case study based on a broader servitization project (see methodology). The main findings were summarized, providing what aspects of this application should be emphasized, what characteristics should be improved and what topics need further research in order to deeply understand the pros and cons of this approach in the PSS context. This case study was performed in an enterprise that aimed to transform their B2B product-based offer in a service-oriented offer, requesting a user-centered approach. In this context, this case represents a first step of the servitization process.

2. Methodology

This research is part of a greater project, which aims to develop a framework for servitization by combining several methods throughout action research [15]. The researchers participated of the broader action-research-based project and the application of DT was performed by means of in-depth participatory case research, a method used for exploratory, descriptive and explanatory investigations [16]. The results of a single case study are presented. This case study aimed to explore the DT approach for supporting PSS development processes, more specifically in a process of servitization. The authors of this work understand the limitations of analyzing a single case study, since the conclusions of a small number of cases cannot be generalized and there is a risk of misjudging isolate events [17].

The questions explored in this case study were "How can DT be applied in the PSS development process?" and "What are the main obstacles to the DT application in the PSS development process?". One DT methodology of literature was selected as a basis for the approach and was adapted during the case study to fit the servitization context. For this adaption, methods of many DT approaches were combined and customized according to the PSS scenario. In order to capture lessons learned and insights, the researchers acted as conductors of the DT approach, facilitating and guiding the DT application and making use of capture techniques, such as personal observation, informal conversations, and attendance of the workshops [18]. Informal conversations were structured by means of a feedback method called "I like, I wish, What if", which was proposed in the Bootcamp Bootleg DT toolkit of d.School [19]. This method structures and encourages constructive feedback by requesting the participants to expose what aspects they enjoyed the most, what they wish could have been different, and what they propose to improve the process.

3. Case description

This case study was performed in a Brazilian mid-size dental and hospital equipment manufacturer, with ca. 450 employees and exportation market of over 30 countries. For confidentiality purposes, this company shall be hereinafter called Equip Co. It has a large product portfolio and high maturity level on developing products. However, it has little experience with services, being limited to a few past failed attempts.

Equip Co. wanted to expand one of its diagnostic imaging products' market share by offering it as a PSS to low-profit customers. This product represented mostly B2B trades and required high expenditures from customers, what limited its market share to few high-profit or high-use customers. This fact contributed to the lost of potential sales that were meaningful to the company's revenues.

The DT approach was selected to support the value proposition stage of the front-end of the PSS development. The team who performed the value proposition stage had a varied background. An industrial engineer, a chemical engineer, an aeronautical engineer and a designer, all of them with experience with the DT approach, composed the researchers' team. Equip Co. also provided four people to join the process, composing the company's team. They worked on the following areas: marketing, technical support, product development, and human resources. Twenty stakeholders were also involved in the process for interviews and prototype testing. The involved stakeholders were current customers, possible future customers, competitors' customers, diagnosis imaging equipment operators, bank institutions, and staff from three different areas of the company.

The process of value proposition was performed through eight workshops. Each workshop lasted from four hours to eight hours, depending on the availability of the company's team. Extra activities were also required from both researchers' and company's members outside the workshops. One researcher always guided the team on the methods application during each workshop.

The DT approach usually starts with the proposition of an initial human-focused challenge, which is proposed to guide the initial steps of understanding and generating empathy. Thus, a challenge was established in order to guide the value proposition process: "How to offer services to the selected stakeholders in order to make them always choose the experience proposed by Equip Co.?".

The core methods for performing the workshop were derived from the Bootcamp bootleg methodology [19]. Methods from other methodologies were also included in the process [20-22], since they were useful in the context of this case study and due to the product focus of most prototyping methods of Bootcamp Bootleg. The approach used in the value proposition was supported by the methods illustrated in Figure 1.

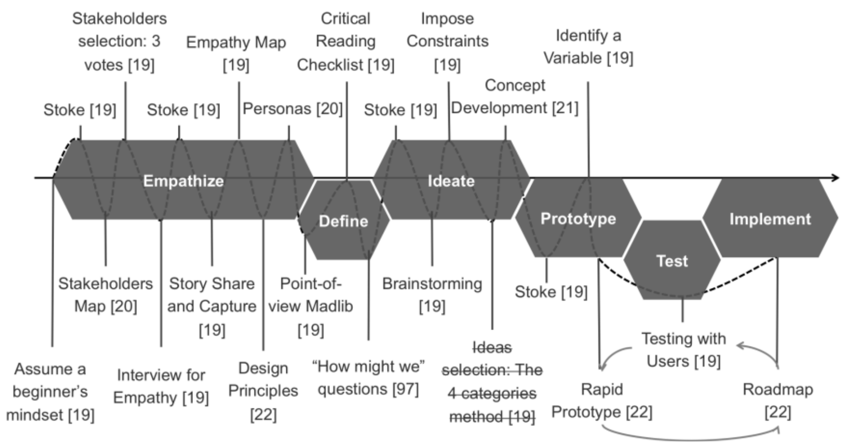

Figure 1. Approach performed in the case study, adapted from the process proposed by d.School [19].

The description of the methods in Figure 1 may be seen in their respective sources. One of the methods is struck through in the figure because it was applied and the results were not considered appropriate for the process goals. Thus, its results were discarded and another method with similar purposes was used instead right after.

Before the process started, a first planning was performed in order to overview how the whole process would be, since process awareness is considered important for a proper flow of the DT approach [19]. However, due to the insights and findings that arose during the process, the planned process was modified as it proceeded. It was expected, since the nature of the DT approach is considered by many authors as nonlinear or even chaotic [21,22]. The re-planning was also expected due to the limited time that was offered by the company.

None of the company's members had ever had contact with the DT methodology before. In order to provide a short introduction on how this approach works, a 90-minute-long exercise ("An Introduction to Design thinking" – The Wallet Project) [23] was performed with the team. It was also useful for introducing the team members, who would work together during the whole process supported by DT.

Performing DT as an approach for the value proposition provided two main results that were inputs to the business model: the market characterization and the PSS concept, composed by the already existing core product.

4. Main findings

The main findings of this case study were summarized in three categories: to be emphasized, to be improved, and to be further explored. The first category highlights positive aspects that were observed during the process or were appreciated by Equip Co.'s members. The second category covered aspects that turned the process less fluid and more difficult, in the perspective of the researchers or the company's team's perspective. Finally, the third category covers all doubts that arose during the process and should be further explored in order to achieve a proper answer.

4.1. To be emphasized

The topics to be emphasized are listed and briefly explained below.

"There is synergy among DT and business model creation methods": DT showed itself to be applicable in complementing business models creation. Outcomes, such as channels, customer relationship and partnerships, may arise from the DT approach. However, DT proved to be particularly useful on providing the value proposition and customers' segmentation of a new offer when applied in synergy with other business model creation methods.

"It is important for the team to be interdisciplinary": Having people with different academic and professional backgrounds eased the process. Having one administrator that worked on marketing, one psychologist who worked with human resources, and one designer provided a non-technical perspective of the product and the offer. Even among the technical members of the team, solutions were created according to the different experiences that each one's background. The need of interdisciplinary teams is also emphasized in DT literature [20,22,24]. It was even more useful for developing a PSS, since many different solutions could compose a single offer.

"The stakeholders map is essential to align who effectively are the stakeholders related to the problem. The team may not surely know who the indirect stakeholders are": Equip Co.'s members were very surprised with the results of the stakeholders map, i.e., a list of direct and indirect stakeholders and their relationship [20]. They stated that their focus was always on the customers and that they did not expect that so many different people could be impacted by or interested in the project. However, for a PSS, it is extremely important to identify and communicate with the proper stakeholders. In the stakeholders map, it was noticed that offering a PSS could weaken the relationship of the company with some of their stakeholders. Thus, they were considered as a critical aspect during the whole value proposition process.

"Interviewing in pairs is important for information register and, when there are novices involved, to guarantee that the necessary information will be reached": Most interviews were performed in pairs composed by one researcher and one company's member. The company's members, however, performed some interviews on their own after the workshops. They reported that the interviews' quality was compromised when they performed them alone. First of all, they stated that being with the researchers, who already had had contact with the DT approach, guided the interview towards relevant information for the problem, since the company's members had no previous experience with the DT approach. Their lack of knowledge and experience with PSS offers also compromised the quality of the information that was obtained. Alone, they said, they used to ask pre-conditioned questions. They also reported problems on recording the information obtained during the interviews when they were on their own.

"Generating questions collaboratively for the interviews seems essential for a good interview planning": The preparation for the interviews that were scheduled in the beginning was done collaboratively among the team members. However, extra interviews were performed after the initial interviews. Those last interviews were prepared by each interviewer alone. When information about the last interviews was shared, the team identified that not all hypothesis were tested nor all complete important information was acquired. Following the guidelines provided by d.School [19] for preparing interviews showed great contribution for the interviews' quality.

"Composing few concepts with all possible ideas before selection may diminish the discomfort of selecting few ideas among many": After ideas were generated with the Brainstorming method in the "Ideate" stage [19], they needed to be selected. At first, one method proposed by the Bootcamp Bootleg [19] was used, where each member of the team should select four ideas, each one belonging to a different previously defined category. In total, more than one hundred ideas were created in brainstorming. The team members, however, felt frustrated about selecting only four ideas and leaving others unselected. Indeed, frustration is expected in convergent moments of the process [21]. Thus, other method was used for selecting ideas, which is proposed by Liedtka and Ogilvie [21]. They propose generating few concepts by combining as many ideas as possible [21]. The method was adapted to the PSS reality and was performed as described hereinafter. All ideas that could be related to PSS were filtered, resulting into eighty ideas. Non-fundamental ideas related to hardware improvement were then separated from service ideas and from fundamental hardware improvement ideas (i.e., adaptions which are essential to allow some services to be implemented), resulting into 45 hardware improvement ideas that were sent to the development department and were not considered in this process. The 35 remaining service ideas and fundamental hardware improvement ideas were synthesized in one table. The team members evaluated each idea regarding two categories: relevance and implementation complexity. Each team member attributed notes from 1 to 5 to each one of the 35 ideas on each category. The most relevant ideas were selected and combined, composing a final complex concept of PSS. This concept was configurable, since most ideas were modular, i.e., could be added or excluded from the concept without compromising other ideas validity. Thus, the concept was configured by means of concept tests with customers, excluding non-promising ideas and improving the promising ones. The team members reported to feel more comfortable on configuring one complex integrated concept than just selecting a few ideas from many.

"DT is useful for improving the existing product architecture and features to support the value proposition": Even though the goal of the process was to servitizate a target product, many improvement ideas (about 45) for the product architecture and features were proposed during the DT approach. Some of the improvement ideas were related to the new PSS offer, that would demand features that were unavailable in the product. However, many product improvement ideas without any relationship to the PSS offer were also obtained. Although literature usually refers to the DT as an approach for new concepts generation, it also contributes on improving existent offers.

"For complex concepts, the tangible and intangible 'chunks' that compose the PSS concept can be distributed in an implementation roadmap covering the following years": After the first idea of the concept was established, the company's members reported fear of not being capable of implementing the complete solution. The roadmap method proposed by IDEO [22] was adapted and used, breaking the concept into tangible and intangible "chunks" for implementation in a timeline. After that, the

company's team reported to feel more confident about implementing the final concept. It may be a proper solution for PSS development, since it can represent solutions with high-complexity level. A roadmap may illustrate the way implementation may be done to support the company on achieving the final PSS offer in a sustainable way. In order to distribute the roadmap, three main stages were created. The first one covered the fundamental configuration, which would allow the commercialization of the PSS offer. Then, the least complex chunks were placed on the second stage of implementation. Finally, the remaining most complex chunks were placed on the third stage.

4.2. To be improved

The aspects to be improved are also listed down and their reasons are summarized:

"It is important to provide a long period of complete dedication to the process. Short workshops surrounded by other commitments may restrict the quality of the process results": The workshops were usually performed once a week. The company's team was not exclusively dedicated to the workshops and time was always very limited. It led to a restriction on the amount of iterations to be performed, compromising the results' quality. The researchers believe, based on their experience with the DT approach, that a longer period in complete immersion would be more profitable.

"It is essential that the same people participate of the whole project to avoid losing tacit knowledge and guarantee that all members have the same knowledge degree about the problem": Some company's members missed certain activities of the workshops, some of which were not critical for information gathering and other activities with critical content. Independently of the type of activities that were lost, a gap on the team's knowledge was created. Although the team tried to level the knowledge whenever it happened, the tacit knowledge generated by the discussions and conclusions made was difficult to transmit.

"The team must be provided with the appropriate mindsets related to the DT approach and to the service-oriented perspective of PSS": The company's team found it hard to work under the appropriate mindset all the time. It was necessary to reiterate how they should think on each situation, both for the DT approach and the service-oriented development. As they acquired more experience, their understanding was improved, and the results quality got better. However, it was hard for the company's members to assume the proper mindset on the beginning of the process.

"The team usually starts the process with a concept in mind. It is important to keep it aside to enhance creativity in the DT approach": Some years before this case study was performed, Equip Co. tried to offer the same core product by means of a PSS offer. This attempt was unsuccessful, worsening their reputation. However, their first concept for a new PSS was the same used in the failed attempt. Even though they were advised that the process should be unbiased and that, even though it could be a solution, it would be discussed only after the ideation stage, the company's members kept continually bringing this issue. It was not rare to see company's members forgetting the goals of the first workshops and discussing their previous concept. This problem could only be overcome after most of the "empathize" stage was complete, when they identified through stakeholders that the former proposition would not work as they thought. After this insight, they became more open-minded about new solutions.

"It is hard to convince the company to dedicate more time in the exploratory steps of the DT approach": One design consultant suggested to the researchers that a 3-month immersion would be appropriate for making field observations and testing

solutions. However, it is not easy for a company to allow its employees to be completely focused on something out of their job scope for three months. Thus, enterprises that desire to apply the DT approach should start by having employees who work full-time in those projects. Maybe some workshops should be held out of the company in order to avoid daily problems and to achieve a comprehensive understanding of the field.

"The interviewees' profiles may be biased": After the interviews, the team concluded that the interviewees' profiles were biased. In fact, the person who scheduled the interviews selected only satisfied stakeholders with a good relationship with the enterprise. It was found out that the DT methodologies did not have a method for avoiding biased interviewees. This problem could have also been overcome if more time was available, since more interviews could have been performed.

"Timidity can restrict service prototyping, which usually requires roleplaying": Since a servitization process is based in service development to improve the original product-based offer and the DT approach has early prototyping as one of its main principles, the team needed to prototype the service concepts. Roleplaying is essential in most service prototyping methods used in the DT approaches [20,21]. Some company's members, though, were timid and did not want to perform roleplaying in front of the long-term customers who were designated to test the concepts. They also believed that customers would not understand the use of this type of technique, since Equip Co.'s did not have the culture of involving clients in the development process. Then, other methods needed to be used and adapted, compromising the concept tests.

"The trust among enterprises and customers is not enough to perform sufficient tests of the concepts": The company's team did not feel confident enough to test the final concepts with real customers due to fear of information leakage. Since testing was required, they selected a few trustable clients. However, their profiles were biased, since they were already their customers and had a good relationship with the company. Therefore, few concept tests were performed with little criticism. Even though some authors in literature provide recommendations on how to improve the participation of customers in collaborative development [25], it is not enough yet to make enterprises feel safe about information leakage.

4.3. To be further explored

Finally, the doubts raised during the process and should be explored are the following:

"Should the whole team have contact with the DT approach and PSS before in order to obtain optimized results?": This doubt is related to one aspect to be improved. If no procedure is able to provide the proper knowledge about DT to the team novices, it should be identified whether only experts should compose the DT team.

"Is external support really necessary for the DT process to run properly?": The company's members reported, in the end of the process, that they did not believe that they would be capable of applying DT on their own. Many authors also suggest that maybe consultancy is required to properly apply the DT approach [11,26].

"How to test with the maximum number of customers with reduced risk of leaking information and enhanced trust by the enterprise?": In order to effectively perform the tests of the concepts, literature still lacks efficient tools to avoid information leakage. Some work has been done providing possible solutions [25], but they were not enough to comprehensively test the concepts. Thus, it should be explored how to increase the amount of testing without significantly increasing risk.

"How to define the ideal time duration for a DT application?": Although experts' recommendation for the DT application is about three months, it would be interesting to explore how long it should really be. It would allow a better planning of the process and make it less time-consuming.

5. Conclusions

The case study performed in this work led to the identification of some aspects that could be emphasized and others that should be improved in this context. It also raised questions that may contribute to the application of DT in the development of a PSS. The case study reached successful results on generating the concept of a PSS in the development front-end, what contributed to the definition of a new business model.

DT proved to be useful on complementing business models creation methods during the generation of new human-centered business models during the servitization process. It was particularly useful on providing the value proposition and the customers' segmentation, but it was able to provide some information on other topics of the business model as well. DT also proved to be helpful on improving the target product architecture and features, even though the approach was focused on creating new services to generate a new PSS offer, complementing the usual statement of literature that design thinking is an approach for creating new concepts.

An overall analysis of the main topics that should be improved shows that they are mainly connected to not assuming the proper mindset, both for the DT approach and the PSS development. The Bootcamp bootleg [19] methodology proposes the mindsets that should be followed continually during the process, such as crafting clarity and embracing experimentation. PSS development also requires a service-oriented mindset, among other behavioral guidelines. Only a few topics were directly related to the chosen methods. Thus, it is possible to say that most obstacles in the DT application were related to not assuming the proper mindset. The profile of the team members may also have influenced on the process with characteristics such as timidity.

The topics for further exploration may be investigated by new case studies. Some of them already have been investigated in literature, but could not be completely answered based on theoretical material for the context of this work. They are important for a proper application of the DT approach in the PSS development process.

Finally, it should be highlighted that, due to the chosen methodology, it is not possible to state that the main findings could be generalized to other situations. However, those findings may support application in similar conditions of servitization and may help by providing possible common problems and solutions.

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A Comparative Between the Design Thinking Approach and the New Product Development Process Early Stages

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Abstract. With the large increase in competitiveness and new technologies, greater speed in the development of new products is required. As the traditional development models can fail to foster innovative products, new approaches are needed. Thus, companies seek new alternatives mirrored in successful cases, such as IDEO. Their process of innovation, called Design Thinking (DT), is mainly focused on the human being. Thus, the objective of this work is to develop a qualitative comparative study between a traditional New Product Development Process (PDP) reference model and the DT approach, with focus in its early stages. Through eight comparison criteria, one can easily see the two different proposals which share the same goal, to be well accepted in the market. Also, there were developed two mental maps of the topics that can be obtained by contacting the authors.

Keywords. Design Thinking; New Product Development Process; Early Stages; Comparative Study.

Introduction

The product development is based on the perception of market needs and technological changes. Several activities are developed, along with the company competitive and product strategies, for the project definition and a product manufacturing process. With increased competitionit is most necessary business agility to develop new products with the new requirements, appropriate to the legal standards and restrictions [1].

Despite the great importance of investment in research and development (R&D), in Brazil, it represents only 1.1% of brazilian Gross Domestic Product (GDP), annually around US$ 24.2 billion, while in the United States it is around 2.7% of the GDP, around US$ 398.2 billion [2]. According to FAPESP [3], China has grown 20% annually in research and development and now ranks second, just behind the United States, with 10.2% of the world scientific production [3]. These countries do not stop investing in ways to understand and improve the design process.

With the highly competitive and rapidly market change, greater agility in product development and making assertive decisions is required. However, it is challenge in the early stages of the New Product Development Process (NPDP). They comprehend the opportunities identification and selection of new product ideas to be developed. They

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are also critical to identify customers' needs and requirements and to transform them into engineering specifications that can be linked and traced back to the customers' needs. According to Cooper [4], the initial phase is of great uncertainty and effect on the outcome. It is responsible for 85% of the cost of the final product and has a low cost if changes occur there. Along the steps, the cost is high and the risk is lower and more controlled [5]. To the extent that traditional approaches begin lack in some situations, industry and academia turn their attention to understand some cases of success and their methods, even not always conventionals.

Thus, there is a demand for new approaches. Back *et al.* [6] cite 14 existing NPDP models, beyond the models adapted by the companies themselves. The search for new trends and the unknown is always motivating. The Design Thinking (DT) is an intriguing new approach, with milestone in the book published by Tim Brown [7], global director of IDEO. However, this new approach does not contain details of how to apply the method. This may be good or bad, because despite not going into details of the activities, one can leave free creativity to apply it in different ways. This causes not knowing how different it is from other development approaches. Moreover, the success stories in books about DT and NPDP generally partially reflect the process done. However, the approach shows positive results and justifies investigation.

From these data, the purpose of this article is to develop a comparative study between the DT and a traditional NPDP reference model, with focus in the early stages. Therefore, this paper seeks to assist the research related to DT and NPDP reference models, facilitating future work, from the knowledge of their differences and equalities. Currently, it was only found a monograph that relates the DT with some formal NPDPs.

1. Methodology

The work was divided into two parts: exploratory research and development of the contents studied in a comparative table between the approaches. The following subjects were investigated and developed:

1. Similar works;
2. NPDP reference models with a choice of a model for discussion of its initial steps;
3. DT study and discussion, based on Brown's work [7];
4. Development of a mental map of the chosen NPDP model initial stages;
5. Development of a DT mental map;
6. Comparison of the two models presented through criteria and developing a comparative table;
7. Results Analysis.

The comparative table is aimed to introduce two methods of different areas, so they can be known and used, together or not, in future studies.

2. NPDP and DT initial stages overview

In this section, some NPDP models will be presented, and then one will be chosen to be compared to the DT. The DT and similar works will also be discussed. There are plenty of different techniques, tools and methods involved, or suitable, to conduct all the possible top levels tasks of NPDP and DT. This work is qualitative and does not get into its details, but they must be dealed on futher quantitative research.

2.1. The NPDP Models

To improve the company's competitiveness, the NPDP needs to be effective. Thus, it depends on the model used for its management [1].

According to Cristofari Jr. [9], there are the generic reference models and the specific reference models. Generics provide an adaptive reference to various conditions and types of processes, like the models proposed by Pahl *et al.* [10], Baxter [11] and Rozenfeld *et al.* [1]. The specific models are considered to have particular characteristics of a sector or industry, like the ones proposed by Romano [12], Paula [13] and Santos [14]. For Cristofari Jr. [9], the differences are barely noticeable in terms of phases, being perceived only on the activity level.

Essentially, all models can be packed in three macro-phases: pre-development, development and post-development. Some stages such as conceptual, preliminary and detailed design are used among all the models [9]. In overview, Buss and Da Cunha [15] conducted a study in which they selected the main activities of the NPDP, regardless of the model: identification and selection of opportunities, generation and selection of ideas for new products, product development and concept evaluation, product performance estimation on the market, marketing strategy preparation of preliminary, product technical characteristics specification, product design definition, construction and prototype testing, production planning, plant preparation, launch strategy definition, market testing and commercialization.

Each model has its strengths and weaknesses. Some have more detail on certain aspects than others. The Cooper's [4] model, for example, focuses in the early stages, but it less details the development stage. The the Rozenfeld *et al.* [1] and Back *et al.* [6] model focus on the development activities [8]. The earlier model presents a higher level of detail and information regarding the tools, methods and practices applyed. Also, it describes the relationships of the various sub-processes involved in the NPDP, from the strategic development to the withdrawal from the market [9].

Among the brazilian reference models investigated, the one that better structure the initial stages is the Rozenfeld *et al.* [1] model. As a result, in this project, it is used as a template. A detailed analysis on its early stages was conducted about it and a mental map was developed. Due to its large size it becomes difficult to read when reduced, thereby, the mental map can be obtained with the authors via e-mail.

2.2. Design Thinking

IDEO is a world's representative of innovative products and services development company. It has large clients such as Procter & Gamble, Pepsi-Cola and Samsung. Through its multidisciplinary culture and process innovation, has led to innovative products such as the Apple computer mouse [16].

Its main approach is to help organizations in the public and private sectors to innovate and grow through focused approach in humans, the DT. Identifying new ways to serve and support people through the latent needs, behaviors and desires. DT is an approach centered on the human being for innovation that uses a kit designer tools to integrate the needs of people, the possibilities of technology, and requirements for business success [7].

For IDEO [18], think like a designer can transform the way organizations develop products, services, processes and strategies. It seeks to bring together what is desirable from a human point of view, what is technologically and economically feasible. Thus, people who are not designers can use tools that encourage creativity so that they can address the challenges of developing new products. They use the skills that everyone has, but are forgotten by most conventional problem-solving practices [18].

The DT, through the ability of integrative thinking (several people from different areas working on the same team and in different disciplines), seeks to translate observations into insight (experience day to day, what people do) and thus develop products and services to improve people's lives. According to Brown [7], we need new choices to create new products that balance human and societal needs. Thus, it must be intuitive and recognize patterns, develop new ideas that have emotional significance, beyond the functional. For this, empathy and knowledge of people is used to design experiences that create opportunities for the involvement and active participation in the development of new products.

A detailed analysis was conducted about it and a mental map was developed. Due to its large size it becomes difficult to read when reduced, thereby, the mental map can be obtained with the authors via e-mail.

2.3. Similar Works

Different articles related to the topic were sought. However, there were found only ones related to DT and design management, and secondly, related to different NPDP models, without comparing the DT and a specific NPDP model.

Separately, was found a case study, applied in Segura's monograph [19]. However, it does not use a particular NPDP model and has no focus in the early stages of the process. From the year of 2009, several books on DT were published. With the aid of books search tools are 9,037 results for books with the keyword "design thinking." In Brazil they have been launched at least two books on the subject. They are: Design Thinking: Innovation in Business [20], and Design Thinking Brazil [21]. Both have tools to use the DT and have a website about the book. As an additional, Viana *et al.* [20] provide for download methods to use in practice, and videos about these tools. However, there is no evidence of his relationship with NPDP models. Thus, it is appropriate to conduct the comparative study of methods used in the DT and the NPDP in its early stages, through the analysis of Brown's work [7] and Rozenfeld *et al.* [1], as prior specific works are unkonwn.

3. Comparative between DT and a NPDP model

3.1. Comparative criteria definition

The comparison criteria definition has been performed based on De Paula and Melo [23] and on Rozenfeld *et al.* [1] model. De Paula and Melo [23] conducted a comparative analysis of six theoretical NPDP reference models and the model used by the company under study. The models were: Wheelwright and Clark [24], Cooper [4], Pahl *et al.* [10], Rozenfeld *et al.* [1], Rosenthal [25] and Back *et al.* [6]. They propose six comparative criteria: Identification of business opportunities (idea generation); Market Analysis (strategy formulation); Project planning design; Definition of product specifications and components; Project tests (design validation); and Prototype (laboratory model). It is noted that not all of these criteria can be considered when seeking to focus in the early stages.

Therefore, in addition to these criteria, were used some topics of each initial phase of the Rozenfeld *et al.* [1] reference model, to get the comparative criteria presented in Table 1. It was seen that the above criteria have similar meaning to topics, that fact facilitates the interpretation between the topics and the model selected. Thus, the criteria are: Opportunity identification (idea generation); Strategic formulation; Definition of customers; Product requirements; Target product specifications; Product alternative solutions; and Prototyping.

3.2. Comparative analisys

Table 1 depicts the main relations between the main research topics ([1] and [7]).

Table 1. Comparative table between the approaches of DT and a NPDP reference model.

Criteria	Rozenfeld *et al.* [1]	Brown [7]
Opportunity identification (idea generation)	According to the company's strategy, the product portfolio is defined concerning the objectives that the company wants to achieve. Board members and functional managers. Also, it can create the Product Portfolio Approval Product Committee or Steering Committee, responsible for managing the product portfolio, deciding which will come out of the market and which projects will be developed.	Through integrative thinking, translates notes into insight to develop products and services to improve the quality of life. The identification of opportunity is through a problem or opportunity that motivates the search for solutions. Different teams working together, for example, designers, anthropologists and engineers.
Steps division	It has two macrofases subdivided into phases and activities. On each project they can be organized on a linear or parallel way. What determines the conclusion of a phase is a set of results that will be used for the next phase of project development.	The three areas of innovation that can be applied more than once, or simultaneously, during design and can be superimposed according to the ideas and directions that the team is exploring.
Strategic formulation	Surveys of technological and market trends, gathering information about consumers, similar products, ideas, setting restrictions. They prioritize projects according to the company's strategy.	Ideas have emotional meaning that, in addition to functional. Designing experiences that create opportunities for engagement and active participation in the development of new products through empathy.
Definition of customers	Internal, external and intermediate customers. They are defined from checklists, direct observation, interviews and focus groups, benchmarking, checklist, questionnaire and/or affinity diagram.	With the definition of the problem or opportunity, observation tools are used, seeking to reveal what people really do, not just listening to what they say. Everyday experience is used and thus defines the customer.

Continues

Table 1. Comparative table between the approaches of DT and a NPDP reference model (continuation).

Criteria	Rozenfeld *et al.* [1]	Brown [7]
Product requirements	Technical specification describes the set of features and the desired performance for the product. Customer requirements in measurable terms, then having the product critical parameters.	Desirable, feasible and viable. Also, they can be determined by technology, budget, or other factors. But human needs are the main focus.
Target product specifications	Guides to generate solutions to the design problem, provide the basis of the evaluation criteria and decision-making. QFD is used.	Desirable, feasible and viable.
Product alternative solutions	Alternatives solution principles are made to the functions that make up each product system separately. Thereupon, are design models produced by combining individual solution principles to form total solutions for the product. Several methods for stimulating creativity can be used, among which the morphological matrix.	Divergent thinking is used. The ideas are tested against each other, making the proposition most daring, creative and attractive. Also, visual brainstorming and thinking techniques are used. Then, with the convergent thinking, the options are eliminated and one of the ideas is chosen.
Prototyping	The working prototype is developed in the detailed design stage, after calculate and draw the SSCs (Systems, Subsystems and Components), specify tolerances, integrate SSCs, finalize drawings and documents.	It can be performed from the first day of the project and also applied to intangibles. They must be produced quickly, with simple and cheap materials, presenting the strengths and weaknesses of the product. From the idealization prototypes are refined with close or equal to the final product materials. Consumers test the prototypes and can generate insights for a different product with a more promising and potentially lucrative market.

It was revealed that at each stage of the Rozenfeld *et al.*[1] model can apply DT tools and techniques to assist the development of the early stages of a new product. In the NPDP, such steps are well defined, it is easier to put them in the form of a table according to their sequence. However, on the DT, as innovation spaces can be used at any time of development, linearizing it gets harder as to synthesize it into a table. Both models point at the same goal: to please and win the customer, but in different ways. In the NPDP, a new product is developed according to the company strategies and the the product portfolio analysis. In DT, in addition, it seeks to transform the people desires and latent needs in products, improving the quality of life.

4. Discussion

Next each topic from Table 1 are discussed qualitatively, in view of its affinity or not between the models. Lastly, the paper comments on the methods used in the research and its representativeness.

In the first option, identifying opportunities, one can see that for Rozenfeld *et al.* [1], the development of a new product derived from the company itself, which it aims to achieve. To Brown [7], moreover, it can arise through insights or identification of a problem or opportunity to improve quality of life. The different teams, working together, can also be a benefit to the company, in order to come up new ideas, more daring, creative and attractive. Emotionally and functionally. In the first case, there is a more reactive approach to the sector, and on the second, a more proactive one to the market.

In the second criterion, steps division, the Rozenfeld et al. [1] model is presented in a linear way, but on each project the acctivities can be planned linearly or in parallel. as each stage generates a set of results which starts the next. This facilitates the design documentation, so that those who make part of it will know how the progress on the product being developed. One of the difficulties is that, when simultaneous engineering techniques are not considered on planning, if one step delays, the others will have less time to develop the product and may delay its launch in the market and generate more costs. The authors give adivices to managers about the advantages on concurrent engineering. In Brown's model [7], the spaces of innovation can be applied as often as necessary and also, simultaneously, according to the direction of the project team. It can change the focus of the product. For this one needs a good project data documentation . Despite the changes on the product focus, one needs to set deadlines for each step, so that it is finalized. In the Rozenfeld *et al.* model [1], some phases can occur simultaneously, and the project focus can be changed. However, depending on the stage that it is the costs will be higher. Thus, one can consider some compatibility and blend ability between models. Collaborative engineering techniques are a fundamental key element when implementing a concurrent/simultaneous NPDP.

In strategy formulation, the third criterion, similar products surveys are conducted, available technologies and the restrictions are set in the Rozenfeld *et al.* [1] model. In DT, the product must have emotional significance, beyond the functional. Becoming this, one of the product requirements. However, in addition to similar research, observational studies are done to know what the customer wants, designing experiences that create opportunities, through empathy. This makes it easier to understand the real needs of customers, which often is not found in similar products. In this case, the two models could be integrated, so it could be carried out a search deeper than actually the customer wants, then formulating a more appropriate strategy for the new product development. These studies complement the definition of customers on Brown's model [7].

In the fourth criterion, customer definition, in Brown's model [7], with the problem or opportunity defined, observation tools are used, seeing what people do, not listening to what they say. Day to day experiences are studied, setting then the customer. The use of the tools are well defined and documented, and may be filmed, recorded and noted according to what is analyzed. This documentation facilitates product development in defining the criteria and the development of alternatives. However, Rozenfeld *et al.* [1] model seek to identify the external, internal and intermediate customers. Customer desires are defined from checklists, benchmarking, checklist and/or affinity diagram. It would be interesting, to apply the DT techniques in this regard. Thus, it could be defined what the customer wants in practice, observing how they use existing products and what they need to do so that the product is really effective in their role. Often, the customer adapts the product for what he wants. Therefore, such adjustments could be identified and applied in the new product.

The product requirements, fifth criterion, are defined by the technical specification which describes the set of desired features and performance of the product by the customer requirements, to define the critical parameters of the product , according Rozenfeld *et al*. [1]. According to Brown [7], human needs are the main focus. The product should be desirable, feasible and viable, it may also be determined by technology, budget or other factors. Both models recommend the focus on human needs, but in Brown's model [7], it is emphasized throughout the process.

In Rozenfeld *et al.* [1] model, the target product specifications, sixth criterion, are guides to generate solutions to the design problem. In the Brown's model [7], these specifications may be considered as the main focus of the project as long as it is desirable, feasible and viable. In this criterion, it would be interesting to apply in Brown's model a better documentation to facilitate the product solutions development.

The seventh criterion in the comparative table is related to the product alternative solutions generation. In the Rozenfeld *et al.* [1] model, alternative solution principles are produced for every function that makes up each part of the product separately. Then, the design models are made by combining each single solution with the other, forming the principles of total solutions for the product by a morphological matrix. In the DT, several ideas are generated via tools, such as the brainstoming or visual thinking. After the ideas generation, the options are eliminated and one of the alternatives is chosen. In both models creativity methods are used to generate various alternatives and then one is chosen. The DT model appears to be more dynamic, but largely depends on the technical capacity of its participants. The system presented by Rozenfeld *et al.* [1] may be more useful for complex technical problems.

To Brown [7], prototyping, eighth criterion, can be performed from the first day of the project and can be applied to intangibles. The prototypes must be produced quickly, easily and wit cheap materials. With it, one can see the strengths and weaknesses of the product early in the design. Consumers test the prototypes and may generate new insights for a different product and can change the focus of the product, seeking a more promising and profitable market. From the idealization phase, the prototypes are refined and near or equal to the final product material. However, a good documentation of all tested prototypes is necessary, so that the final product has the maximum strengths observed. To Rozenfeld *et al.* [1], the prototype use is emphasized only in the detailed design stage, when all the product requirements and ideas are already determined. From the beginning, prototypes can be applied in NPDP models, using simple and inexpensive materials, so one can have more visibility on how the product will materialize and thus analyze their negative and positive aspects of functionality, generating more data and facilitating the development of the new product.

The Brown's model [7] appears to be more dynamic, however, as the literature is very basic in the matter of how to do, it can be considered less formal. In complex projects, formalism and the organization may be requirements for success. The reference model, in contrast, is more detailed. Therefore, to develop the balance between the two models comprises the new product development managers challenge, when planning their projects.

Despite the generality and lack of research tests, this project may be the beginning of a thorough study regarding a mix betwee DT and NPDP concepts. In addition, the mental maps developed can be useful for others. Experimental researches must be driven using quantitative methods to measure the effectiveness on each aproach. This work gives an overview (Table 1) on what may be further investigated encopassing the qualitative perception.

5. Final remarks

This study achieved its goal of building a comparative study between the NPDP and the DT. From eight comparison criteria, according to the initial stages of the NPDP, the approaches are compared and discussed point by point. The two methodologies with different proposals and focus can be seen, also it is noted that they seek the same goal: to win customers and to have a well accepted product on the market.

The possibility of integration of approaches, especially the DT practices in the PDP, is elucidated. Among the different possible forms of integration between the development approaches, prototyping is highlighted. This is because, through rapid prototyping, simple and cheap materials, one can have greater visibility of how the product will materialize, and can observe their strengths and weaknesses, and if its functions are being well implemented from the beginning a new NPD project. With the product functions being tested since the beginning of the project, the product can best satisfy the customer, achieving a more promising and profitable market.

This study also provides a comparative table and two mental maps produced by the authors, that can help further research on the subject and on the specific authors on discussion. Other future work can be carried out comparing all NPDP and DT steps or involving practical applications and case studies.

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Collaborative Maritime Transportation Under System Dynamics Simulation

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Abstract. In this paper, a model is presented to analyse the systemic effects of collaboration among manufacturing industries that use maritime transportation for export purposes. The Collaborative Logistics era and Collaborative Transportation Management were researched to validate the proposed study and to obtain data for use in the model. Entrepreneurs and specialists were interviewed. Subsequently, a study was conducted on System Dynamics (SD) methodin order to analyse systemic effects from the collaborative policies of manufacturing industries, which increase bargaining power when the industries are allied to each other and can reduced maritime freight rates. This work helped to elucidate the importance of using an interdisciplinary approach to address problems in maritime transportation.

Keywords. Collaborative Maritime Transportation, System Dynamics, manufacturing industry, collaboration, collaborative logistics.

Introduction

Supply chain management plays a role in the coordination of several relationships in the supply chain, which is defined as the organisational networks that create services and products for the final consumer. Novaes presents the typical formulation of a supply chain in terms of the material flows derived from inputs, components and goods [1]. Historically, these flows among the participants of the supply chain present conflicts in the business channels. Each link of the chain seeks to minimise its individual costs, which does not usually correspond to the global optimum of the supply chain. This fact is becoming increasingly difficult to ignore, so to reduce costs, increase efficiency and obtain competitive advantages, enterprises are being forced to rethink their procedures, to use reengineering techniques and to redefine the relationships and the models of their supply chains.

The global concept CPFR (Collaborative Planning, Forecasting, and Replenishment) emerged within this context at the end of the 90s. This concept expresses the integration of several participants into the supply chain to ensure increases in sales, inter-organisational alignment, and operational and administrative efficiency. An application of CPFR occurs in the transportation area, under the name CTM (Collaborative Transportation Management). There is a consensus among

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specialists that this tool has a great potential for reducing costs and risks, for increasing service and capacity performance, and for obtaining a dynamic supply chain [2].

However, there has been little discussion so far on the resolution of collaborative maritime transportation problems by manufacturing industries. Thus, this paper presents a model to analyse the systemic effects of the collaborative policy of manufacturing industries that use maritime transportation for export purposes, by using the main strategic and operational parameters involved.

1. Collaborative logistics and the Collaborative transportation management

Since the introduction of the ECR (*Efficient Consumer Response*) around 1993, the supply chain participants have tried to view their businesses in the light of the ECR concept, which involves all the participants working together principally through communications networks formed by EDI (*Electronic Data Interchange*) [3]. Tacla explains that while few reports in the literature corroborate the emergence of a "collaborative logistic" phase, reports exist on a "new era" [2].

Similar to CPFR, Collaborative Transportation involves the flow of information and processes from suppliers and buyers who collaborate with carriers or 3PLs to provide effective and efficient cargo delivery. Conceptually, enterprises can join the Collaborative Transportation system with or without using CPFR. However, Collaborative Transportation has been referred to as the "missing link" in the realisation of the collaborative supply chain. Without effective forecasting ability, CPFR can handle order forecasts inaccurately; thus, Collaborative Transportation provides the next critical step after order generation by CPFR. See Silva et al. [3] for detailed information on CTM implementation. Few publications exist on more applied collaborative transportation methods, such as mathematical programming and simulations [2][3].

2. Maritime transportation mechanisms for the export of manufactured goods

Silva et al. [3] have discussed that negotiations may be initiated by a manufacturing industry (1), which may act alone, being responsible for all the arrangements in the distribution chain (follow the blue-coloured flow in Figure 1). In this situation, the manufacturing industry hires a land carrier (4) (if the industry does not own a truck fleet) to transfer the manufactured goods from the industry to the port. There is also a possibility, or in many cases a necessity, of first transferring the manufactured goods to a warehouse (3) to maintain a stock which can be used to quickly solve delivery problems or of retaining the cargo up to the time that all the bureaucratic export issues are resolved. The industry also chooses the port of origin, at which time freight prices are negotiated with shipowners (7) and a shipowner is selected choosing one of them to transport the manufactured goods.

At this stage, it is quite common to hire a NVOCC (6). This agent is responsible for managing the maritime transportation demands of several industries to negotiate with shipowners on freight prices and the availability of ships to the destinations of the industries' manufactured goods. The manufacturing industries also need to determine the most appropriate port of destination port (8) for delivering the goods to clients (11). To fulfil deliveries, the manufacturing industry must also hire land carriers (10) to transport the goods to intermediate warehouses (9) or to the final destinations in the relevant country.

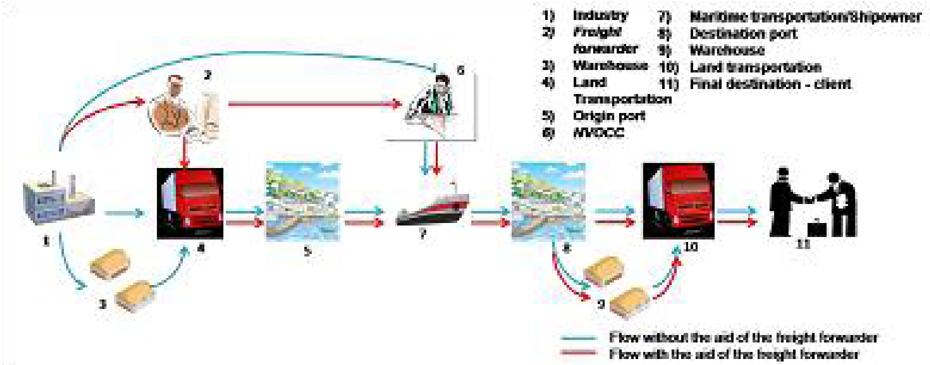

Figure 1. Export mechanism stages, Source: Silva et al. [3].

The red-coloured flow in Figure 1 is almost the same as the blue-coloured flow except for the presence of the freight forwarder (2). This agent is hired by the manufacturing industry to handle all the contracts and control all the stages in the distribution chain. This is typically practiced by small and medium industries that do not have expertise in these processes, such that the freight forwarder, who manages the transportation demand for several industries, can negotiate intelligently on their behalf.

The literature on the determinants of international transport costs has been growing recently. Interest in this topic is motivated by the need to better explain economic development and international trade patterns and to identify means of reducing transaction costs [4]. Most international trade continues to involve sea transport, so that ports are crucial nodes in global shipping networks. Thus, good planning of distribution logistics can achieve the following: reduced storage time and costs, reduced shipping time, and reduced delivery problems to better serve the sales contract. Costs can be reduced at several stages of the distribution process. Stopford has proposed that the stage at which the freight price is set is an influential key to defining supply and demand in maritime transportation [5].

Silva considers the actual practices used by shipowners in setting freight prices to be significant [6][3]. Typically, shipowners set prices for sea shipment by a regular liner in a Freight Conference. Consequently, the conference apparently maintains a monopoly over the trade routes. Thus, the manufacturing industries have no bargaining power during individual negotiations with shipowners to obtain better prices. This is where collaboration can be used to create groups of industries with the same goal [7]. These groups can negotiate with shipowners to deflate the shipowner market power and obtain economies of scale and other benefits such as significant time to pay the freight and free shipping time.

3. Modelling the Collaborative Transportation Problem

Modelling was selected as the experimental method in this study and simulation was used as the computational technique. Next, a systematic literature review was conducted on studies using *System Dynamics* (SD) for the simulation method.

The SD method was chosen for two main reasons. The first reason was that dynamical complexity was involved in the problem under consideration, where the actions of some agents cause reactions by other agents. The second reason was that proposed policies needed to be simulated quantitatively to evaluate their impact on the goals of the agents involved. SD was developed to solve problems characterised by dynamical complexity, i.e., systems where the actions of a pre-determined agent cause reactions by other agents, which is also known as *feedback*. Is it valid to mention that the numerical parameters presented in all the equations were defined after a curve fitting analysis. The data used in the curve fitting phase were obtained in the literature and also with the interviewed port-industries' managers.

3.1. Behaviour of manufacturing industries

The starting point in the model is to understand the operation of manufacturing industries, as well as how collaborations form among industries based on the market freight price. Mankiw has proposed that the product price is the main factor in determining product demand [8]. Therefore, the behaviour of the industries was modelled using Vensim® software from Ventana Systems enterprise, Inc. (version DSS).

The number of industries considered in the analysis is modelled as a stock variable, *Industries* (*Ind*). This type of variable is an accumulation variable that characterises the state of the system, providing information with which the entrepreneurs can make decisions and take action. A stock variable is typically modelled by a rectangle (i.e., a container that stores stock). This type of variable is only changed by flow rates, inputs or outputs: *ingress of new industries* (*ini*) and *abandonment of industries* (*di*) are both stock variables.

Thus, the accumulated number of collaborating industries (*Ind*) is expressed as the initial number of industries ($Ind(t_0)$) added to the integrated rate of change of the number of industries ($\dot{I}$) in time, as in Equation 1:

$$Ind(t) = Ind(t_0) + \int_{t_0}^{t} \dot{I}\,dt. \qquad (1)$$

The $\dot{I}$ variable represents the number of new industries that have ingressed into the collaboration (*ini*) and the number of industries that have been abandoned (di) at time t, as in Equation 2:

$$\dot{I} = ini - di. \qquad (2)$$

The *ini* variable varies with the profit ratio (*ral*) obtained in a determinate time *t*. The ratio between the collaborative freight price (*Pref*) obtained and the market maritime freight value from individual negotiation is denoted by *ral:* using a value of $ 100,00 for the market maritime freight gives

$$ral = pref / 100. \qquad (3)$$

Thus, it is assumed that

$$ini = \begin{cases} 0, & ral > 1 \\ 8{,}1079 \cdot \exp(\text{-}2{,}179 \cdot ral), & ral \le 1 \end{cases}, \qquad (4)$$

i.e., if the profit ratio is greater than 1, the collaborative freight price is greater than the individual freight price that can be obtained by the industry and the ingress of a new industry into the collaboration is not viable. The demand curve cannot be simply defined; therefore, an exponential curve is chosen to quantitatively model variations in the freight price in practice. The specialists interviewed claimed that using this curve it is quite common in actual market practices.

The expected number of *di* is also a function of *ral*: if ral≤0.58, then d_i=0, otherwise

$$di = 0{,}0801 \cdot \exp(2{,}1502 \cdot ral), \tag{5}$$

i.e., a large *ral* implies that it is impractical for industries to participate in the collaboration, resulting in a larger number of abandoned industries. As prices do not increase infinitely in practice, $Pref$=55is set for Ind>100; for all other values of *Ind*, $Pref$ is given by Equation 6:

$$Pref = 100{,}38 \cdot \exp(\text{-}0{,}006 \cdot Ind). \tag{6}$$

3.2. Behaviour of ships

To better understand the behaviour of shipowners who make ships available for maritime transportation, a stock-flow diagram is used to model the mechanism of making a ship offer in terms of the market freight price. The number of ships(*Nav*) is given by the initial number of ships(*Nav*(t_0)) plus the integrated rate of change of ships ($\dot{J}$) with time, as in Equation 7:

$$Nav(t) = Nav(t_0) + \int_{t_0}^{t} \dot{J}\, dt. \tag{7}$$

The variable $\dot{J}$ denotes the number of new ships that ingress into the collaboration (*inn*) minus the number of abandoned ships (*dn*) at time *t*, as in Equation 8:

$$\dot{J} = inn - dn. \tag{8}$$

The variable *inn* and *dnn* vary with $Pref$:

$$inn = 0{,}0669 \cdot \exp(0{,}0441 \cdot Pref). \tag{9}$$

$$dn = 8{,}6679 \cdot \exp(\text{-}0{,}043 \cdot Pref). \tag{10}$$

Last, the offer curve is defined by the freight price resulting from the number of ships available in the market. Thus, for Nav<1, $Pref$=50, otherwise

$$Pref = 55{,}206 \cdot \exp(0{,}006 \cdot Nav) \tag{11}$$

3.3. Collaboration between industries and the availability of ships as a function of the maritime freight price

A stock-flow diagram is modelled to simultaneously analyse the behaviour of the offer-demand system influencing collaboration among the manufacturing industries. The diagram uses a different definition of the variable *Pref*. This variable was an auxiliary variable, but has been changed to a stock variable. This change is made because the price does not change instantaneously.

As a stock variable is changed only by the inflows and outflows [9], the *demand rate* (*tdem*) and the *offer rate* (*tof*), representing the demand and offer, respectively, are both considered to be inflows. The variable *tdem* denotes the number of industries (*Ind*) that exist at a given time, but this value is converted into the number of ships (*Nav*), to unify the analysis. Thus, $tdem = Ind/3{,}33$ and $tof = Nav$. In the proposed diagram, the variable *dn* assumes the values in Equation 12:

$$dn(tof,\, tdem) = \begin{cases} 2, & tof/tdem \geq 1, \\ 1, & tof/tdem < 1 \end{cases}. \tag{12}$$

This ratio indicates that if the offer rate is greater or equal to the demand rate at a given time *t*, 2 units of ships leave the system to try to reduce the freight price. Otherwise, when the demand rate is greater than the offer rate, only 1 ship leaves the system (it is assumed that a ship can always leave the system, even when business is viable).

Apart from such considerations, $Pref$ is expressed by the initial value of the freight price ($Pref(t_0)$) plus the integrated rate of change of the freight value ($\dot{M}$) over time, as in Equation 13:

$$Pref\left(t\right) = Pref\left(t_0\right) + \int_{t_0}^{t} \dot{M}\, dt \tag{13}$$

where, the variable $\dot{M}$ is determined by *tof* and *tdem*.

3.4. Hinterland capacity

Novaes et al. have discussed that ports present several critical problems that contribute to high logistics costs, one of these problems being the lack of port capacity [10]. Thus, considering that maritime transportation operations require an area for container receipt and storage, part of the hinterland, a corresponding variable was included in the model.

Thus, the *hinterland capacity* was modelled as a stock variable, *CapHin*, representing the accumulated container storage capacity in units of containers. This variable is affected by the inflow known as *expansion area* (*amp*), which represents the additional capacity that the system receives at a given time. This additional capacity may occur, for example, when the hinterland managers, recognise a trend in the growing demand for space and consequently anticipate new construction or yard availability.

Based on this information, *CapHin* is expressed as the initial value of the hinterland capacity ($CapHin(t_0)$ plus the integrated rate of change of *amp* over the time *t*, as in Equation 14:

$$CapHin(t) = CapHin(t_0) + \int_{t_0}^{t} amp\,dt, \tag{14}$$

i.e., if the rate of occupation of hinterland capacity (*toc*) is greater than or equal to 75% of the capacity being used, the capacity is enlarged by 300.000 containers (a randomly chosen value), otherwise nothing is performed based on the demand for the available capacity.

Capacity expansion is the process of adding facilities over time to satisfy rising demand. Decisions to expand capacity expansion usually correspond to a massive capital commitment. Efficient capital investment involves making appropriate decisions on undertaking expansions, such that demand continues to be satisfied over an extended time period with a minimum discounted lifespan cost.

The basic way to minimise project lifespan cost is to compute the Net Present Value (NPV), where investments and costs are discounted using a continuous interest rate, r. The revenue generated is calculated from the monthly gain per container in storage in the hinterland. Then,

$$R_j = tdemc_j \cdot prearmaz, \tag{15}$$

where *prearmaz* denotes the monthly price paid for storing a container in the hinterland. The incident cost in period j is calculated by considering the investment costs of the hinterland area capacity expansion.

Learning curve theory states that as the quantity of units produced double, labour costs decrease at a predictable rate. The experience curve, on the other hand, is broader in scope because it encompasses far more than labour costs. Here, each time the cumulative volume doubles, value added costs (including construction, administration, logistics, etc.) fall by a constant and predictable percentage. The experience curve is mathematically described by a power law function:

$$I^{(m)} = I^{(1)} \cdot m^{-\theta}, \tag{16}$$

where $I^{(1)}$ is the building cost of the first unit, $I^{(m)}$ is the investment value of the m^{th} unit, and θ is the elasticity of the building cost with regard to the number of units built in sequence.

3.5. Export incentive

Conscious of the importance of expansion for Brazilian manufactured products, an auxiliary variable, known as the *export incentive* (*incexp*), is included in the proposed model to represent the incentive for increasing exports to evaluate the impact created by the industries that ingress into the collaborative transportation system.

The variable *incexp* was modelled as a “PULSE” function (in Vensim® language). The (dimensionless) PULSE function (with arguments of the initial time and duration) returns the value 1 at the programmed initial time and remains at this value over the programmed duration of time, while taking the value 0 for all other times.

3.6. Impact of the maritime industry

When modelling the collaborative behaviour of the industries in the maritime transportation system, the impact of the maritime industry on the system must also be considered. The discrepancy value in the maritime fleet, *discrep* , can be understood as the difference between *tdem* and *tof*. The *discrep* variable is related to the number of ship orders (*encnav*) to be filled per time period, and the *encnav* variable is an inflow to the *Cartec* variable. *Cartec* is a stock variable representing the existing construction and order charter, i.e., the accumulated number of ships that are under construction at a given time. *Cartec* is also affected by the outflow *ships delivery* (*entnav*).

As ship construction is a hard work, a delay time between the ship order and the time of delivery must be taken into account. This delay is modelled in Vensim® language by the DELAY1I function (with arguments of the input value, duration, and initial value), which produces an exponential delay of the input value.

4. Results

The computational simulation results are presented in this section. These results helped to elucidate the mechanism for collaborative maritime transportation.

4.1. Analysis of the behaviour of industries

At the start of the analysis, an initial value of $Ind(t_0)=20$ is used with a high *Pref* (around $90,00). For this case, the initial rate *di* is relatively high (i.e., it is not attractive for industries to ingress into the collaboration system because the cost of collaboration is higher than the individual cost), whereas the rate *ini* is relatively low (*di* and *ini* are inversely proportional to each other).

As *Pref* is reduced, it becomes worthwhile for industries to ingress into the collaboration system: therefore, the rate *ini* is high, exhibiting exponential growth and increasing the number of industries *Ind*, which in turn reduces *Pref*, closing a *Balance Looping*. While the collaboration is favourable for industries, the rate *di* is reduced.

4.2. Analysis of the behaviour of ships

Initially *dn* is high because shipowners offer a small number of ships at low freight prices. As the freight price increases, the new ships ingress flow also increases, which in turn increases the number of available ships on the market, closing a *Reinforce Looping.* Thus, the flow of abandoned ships is also reduced.

4.3. Behaviour of industries and ships as a function of the maritime freight price

When the freight price is initially low, it is not worthwhile for the shipowners to put new ships on the market: therefore, the number of ship offers remains constant until the freight price starts to increase and it becomes favourable for new ships to ingress into the market. This situation continues until the freight price reaches a maximum (approximately at time 20), when the offer is greater than the demand, which starts the reduction process. This action stops the ingress of new ships (approximately at time 30).

The demand for ships by industries in collaboration initially grows at a low rate (*ini*). As the flow decreases, the rate of increase of the stock also decreases. This is because the stock level of *Ind* is also increasing even while the flow *ini* is decreasing, so that the positive flow of stock results in an increase in the stock value.

The flow *ini* indicates the slope of the stock *Ind* with time. Over the time period 0-20, the incident flow of the stock is decreasing, so that the increment in the stock value also decreases; however, over the time period 20-45, the incident flow is increasing, resulting in a rise in the stock. Thus, the slope of the stock at a particular time is assumed to be equal to the resulting flow (input-output) at this time. Thus, the stock slope at a given time is equal to the slope of the tangent line slope at this time. As the time runs, the gap existing between offer and demand of ships, reduces, reaching a market balance.

The variable *tof* is also controlled by *Pref* and changes with two flows: *new industries ingress* (*inn*) and *abandonment ships* (*dn*). As *Pref* increases, the rate *inn* also increases as the shipowners try to maximise their profits. The excess ship offers in the market reduce freight prices because the collaborating industries have greater negotiating power. The freight price continues to drop until the number of ships offers is low. Then, the shipowners start to increase the freight price again. The cycle repeats in time until an equilibrium is reached (around time 140).

4.4. Analysis of the behaviour of the hinterland capacity, export incentive and the impact of the maritime industry

As *tdemc* increases, *toc* also increases. In this case, the *hinterland capacity* starts to be used up until (t=36), toc=0.75, i.e., 75% of the hinterland capacity is used resulting in the capacity is being expanded to 300.000 containers. The new available capacity is CapHin=600.000. At this time, the occupation rate decreases and this procedure repeats over the time until the containers will not be sufficient, necessitating a new expansion strategy. Thus, there is a particular time period where investment can reduce cost and increase capacity utilisation.

During the analysis of a project, exogenous variables can emerge resulting in deregulation of the system. In the proposed model, the variable *export incentive* contributes to *new industries ingress*, increasing the demand rate. This in turn increases the gap between the demand rate and the rate of offers, increasing the freight price. In addition to the price increase, an export incentive produces a congestion in the hinterland area, requiring further capacity expansion that was not considered in the original project.

The maritime industry tries to reduce the fleet discrepancy when meeting the existing demand for ships. Some construction orders are filled over this time and some deliveries are also made. As the construction time for a ship is set at 16,7 months, there is a delay between the time of placing the construction order and the time of delivery. The delivered ships become part of the available ship stock and directly influence the rate of offers. When the rate of offers is greater than the demand rate, the freight price decreases and the ingress of new ships essentially stops. The reduction in freight price is the ideal condition for new industries to ingress into the collaboration, increasing the demand rate over the offer rate. Such a condition increases the freight price and also starts the ingress of new ships into the maritime industry again.

5. Final considerations

Despite the simplified model, one of the more significant findings to emerge from this study is the importance of each variable in isolation, in addition to the impact on the system following a change in these variables. This change was made using sensibility analysis. Following a literature review, consultation with entrepreneurs, modelling the problem and analysing the numerical results of the system behaviour, the explicit and implicit benefits of the collaborative maritime transportation system were identified: shared administrative costs, reduced maritime freights, greater *free-time* on shipment, greater time to pay the freight, greater influence over carriers, import and export constant flows, increased offers of service by the shipowners and ports, and improvement in the hinterland, among others.

The results of this study show that collaboration presents a good opportunity for industries and a variety of subjects related to the theme of this paper have not been mentioned. Therefore, there are several options for extending this work: expanding the proposed model to include all the agents involved in the maritime export chain shown in Figure 1, as well as improving the details of the agents behaviour; repeating the study after obtaining more quantitative actual data; performing the same study in a different industrial sector in Brazil for comparison; proposing a collaboration index; and improving the SD study to better analyse the models for collaboration formation. Thus, the formation of a collaborative network should be consolidated to improve the efficiency of the logistics and enterprise profits, as proposed in the collaborative transportation approach.

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Collaborative Design and Manufacturing of Prosthodontics Wire Clasp

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Abstract. The core idea behind the concurrent engineering is an integration of upstream and downstream activities of design/manufacturing in order to produce better products in a timely manner. Digital engineering is one of the critical approaches towards this integration, and this approaches enables the promising area of digital dentistry. Digital dentistry is defined as a dental technology or device that incorporates digital or computer-controlled tools, for example, dental CAD/CAM systems. This research focuses on the area of dental wire clasp, which has been manufactured by manual bending operation performed by the skilled dental technicians. Normally, a team of dental doctor and dental technician works collaboratively to design and manufacture the dental wire clasp. However, the accuracy of the bending operation is inconsistent and depends mainly on the expertise of the technicians. This paper describes the current situation of dental wire clasp manufacturing, reviews some of the innovative computer-aided wire bending systems, and proposes a framework of collaborative prosthodontics wire clasp design and fabrication using an idea of virtual engineering approach in digital dentistry.

Keywords. Digital dentistry, Dental wire clasp, CPS, IoT, CAD/CAM

Introduction

The core idea behind the concurrent engineering is an integration of upstream and downstream activities of design/manufacturing process in order to produce better products in a timely, and effective manner. Digital engineering is one of the critical approaches towards this integration, and its promising areas are commonly manufacturing industries. However, thanks to the advancement of CAD/CAM technologies [1], digital dentistry could be another promising area of this integration. Digital dentistry is defined as a dental technology or device that incorporates digital or computer-controlled tools, for example, dental CAD/CAM systems [2].

When we look at the dental wire clasp manufacturing, it has been traditionally performed in hand-made operation by skilled dental technicians. One of the critical issues of manual bending is that the accuracy of the bending operation is inconsistent and depends mainly on the expertise of the technicians. Therefore, some CNC-based wire bending systems for dental arch wires have been proposed as an innovative approach to digital dentistry. However, these machines are mostly based on flat shape

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bending, which is not compatible to fabricate the 3D shape of dental wire clasps. The first issue of this study is to design and develop a computer-controlled dental clasp bending system.

It is true that dental CAD/CAM systems technically support the dental treatment in these days in an effective manner. However, their objective is not on the integration of upstream/downstream activities, but mainly focuses on manufacturing of dental restorations. Since network-based technologies, such as Internet of Things (IoT) [3] and Cyber-physical systems (CPS) [4] have been available these days, these technologies could also be applied to digital dentistry to implement a cyber-dental system, which is the second issue of this study.

Reviewing these two issues mentioned above, this paper proposes an idea of cyber-physical dental wire bending system, which integrates an idea of 3D CNC wire clasp machine and an idea of collaborative working for the integration of upstream/downstream activities of dental treatment.

1. Dental CAD/CAM system using digital manufacturing

Digital dentistry technology is attracting the attention not only of the dental technicians and dental doctors, but also of patients for its emerging technology towards an innovative dental treatment [5]. Dental CAD/CAM system is one of the promising fields of digital dentistry, of which process flow is shown in Figure 1, where a dental CAD system and a dental CAM system play the two central modules in the process.

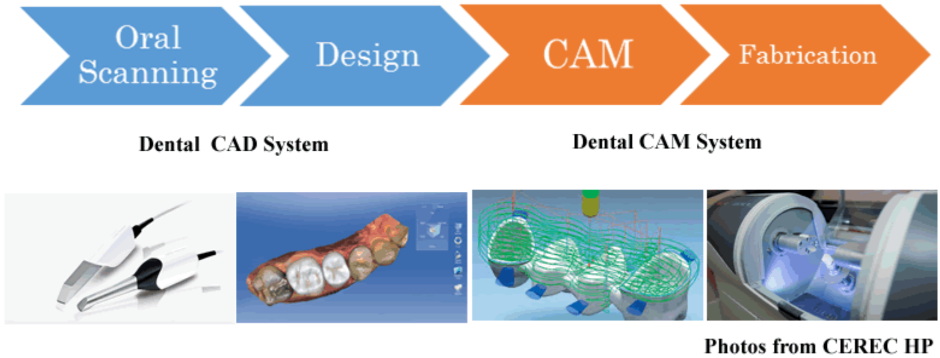

Figure 1. A typical process flow of dental CAD/CAM system.

Initiated by the first commercialization of Cerec system [6], several dental CAD/CAM software products are on the market, such as ISUS, Delcam, Renishaw, SUM3D, MillBox, WorkNC, etc. As for the manufacturing processes in CAD/CAM dentistry, just like industrial CAD/CAM fields [7], subtractive processes such as CNC milling as well as additive manufacturing processes such as 3D printing are used.

As opposed to the conventional method of dental impression, a dental CAD/CAM system enables to process a more accurate, quick and flexible dental treatment [8]. However, the dental CAD/CAM system requires extra time and work on the part of dentist, and the manufacturing cost is much higher than conventional restorative treatment, which may be one of the issues remained to be solved.

One of the potential advantages of dental CAD/CAM system, however, would be the availability of virtual cyber-dental space, where patient, dental technician and dental doctor could share treatment information and virtually work together. The current dental CAD/CAM system, however, mainly focuses on the design and creation of dental restorations such as crowns, crown lays, veneers, inlays and onlays, bridges, dentures, etc. Therefore, the potential usage of cyber-dental space still remains unused.

2. Cyber-physical dental system based on virtual operation

One of the approaches of cyber-physical dental space can be seen in the application of guided surgery of implant operation. A computer guided implant treatment system offers dental doctors a comprehensive 3D system for accurate and predictable implant treatment[9]. Dental implant operation can be manipulated in virtual space, its surgical template guide can be virtually designed, and physically manufactured to be used in the actual implant operation.

The authors have proposed an idea of collaborative framework using cyber-dental space for implant operation simulation. Figure 2 shows an image of dental implant operation using the collaborative cyber-dental space, where dentist and patient share the treatment information and work together in a collaborative cyber-dental space.

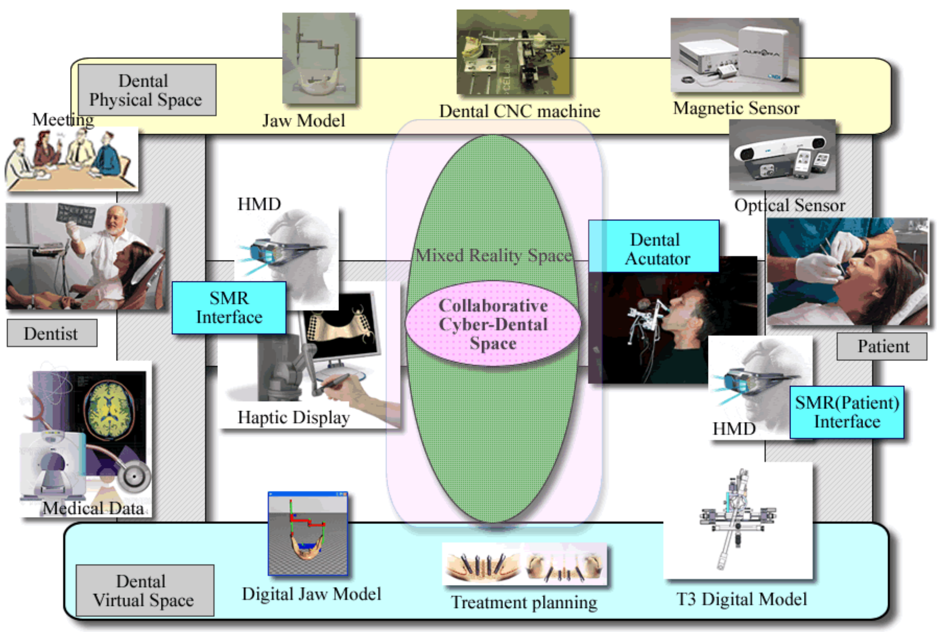

Figure 2. A framework of cyber-physical dental system for dental implant treatment.

In this framework, a dentist and a patient share information in the mixed reality-based collaborative working space. Prior to the actual treatment of implant operation, a dentist prepares a dental treatment design and shares it with a patient so that the patient could understand how the operation is supposed to be performed. The collaborative working space also functions as a reliable space which enhances the feeling of trust between the patient and its doctor.

This framework is based on an idea of implant operation, where digital engineering could offer substantial benefits to both dentists and patients. Based on the idea of this framework, this research applies it to dental wire clasp design [10] and manufacturing using a new type of CNC wire bending system of which process flow will be presented in Section 3, and proposes a collaborative framework for prosthodontics wire clasp design and fabrication, which will be presented in Section 4.

3. A process flow of CNC dental wire bending system

Industrial wire bending machines [11] are available on the market to fabricate bended wire products with different materials, size, diameter, etc. Several types of CNC wire/pipe/tube bending machines are developed by industrial bending companies [12]. For example, tube bending machines can make automatic bending operation based on the CAD/CAM design data [13]. These bending machines, however, are basically heavy and big because they are made for industrial applications. Incidentally, the technology in those industrial bending machines could be applied for denture fabrication in dentistry. However, these machines are too big in their size and not suitable for dental applications.

Ideally speaking, the dental CNC bending machines should be compact as a table top in its size so that it could be used as a chair-side operation. Recently, a desktop size CNC wire bending machine [14][15] has been put on the market to work as if it were a 3D printer of wire bending to fabricate a variety of simple shapes by a simple operation. However, the wire clasp bending in dentistry is very much complicated in sizes and shapes, and requires a high degree of accuracy to ensure the perfect fixation of clasp to patient's mouth. Therefore, these machine are not suitable for dental wire bending applications.

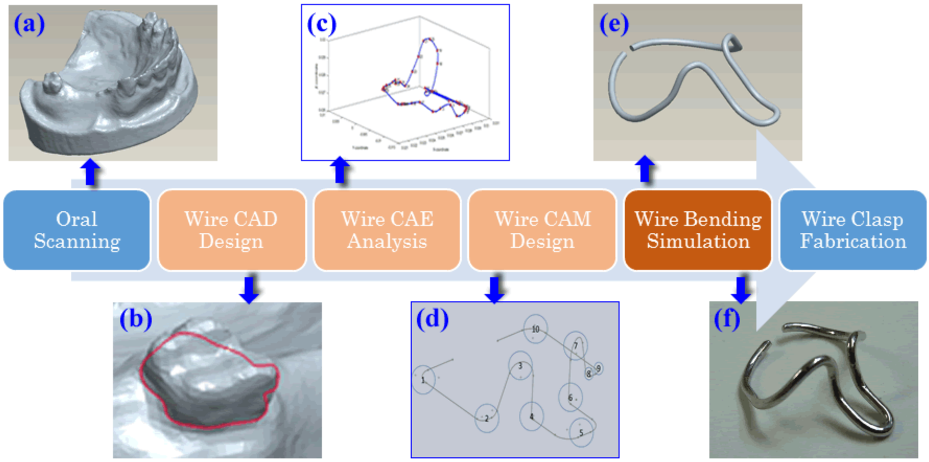

Figure 3. Process flow of dental clasp wire bending system.

In general, the accuracy of the bending operation is not always consistent and fundamentally is depended heavily upon the skills of the dental technician. Incidentally, innovative attempts to automate the wire bending process have been made in several projects which proposes wire bending machines, for example, LAMDA robot [5], endodontic micro robot [16], Cartesian robot, orthorobot [17][18], Suresmile robot[19][20], etc. However, all of these approaches are flat shape bending, which is not compatible to fabricate the 3D shape such as dental wire clasps.

Considering the above mentioned circumstances, this project proposes an idea of CNC dental wire bending machine system, which could design and manufacture a dental wire clasp based on the following process flow. A dental CAD/CAM system mentioned in the previous section enables design and fabrication of dental restorations such as crowns, bridges, etc. The CNC wire bending system in this research enables design and fabrication of tailor-made dental wire clasps. Figure 3 shows the overview of design and fabrication process flow of dental wire clasp bending system proposed in this study.

The bending process is performed in the following six steps (a)-(f). As the first step (a), oral scanning with a 3D digital scanner makes the raw shape data for design of dental wire clasp as shown in Figure 3(a). The target object in this figure is a dental impression created in a conventional dental impression technique, which could also be possible by a direct oral scanning using a handy digital scanner.

The second step (b), a dental clasp wire design can be made on the scanned digital model by a digital engineering approach [2]; For example, a dental technician traces the target clasp curve by a digitizer, a haptic device, or even a mouse as shown in Figure 3(b). However, the 3D curve is designed in a 3D virtual space where shape recognition is very difficult in general. Therefore, a haptic device is an effective tool to design/modify/finish the curve design in 3D virtual space [21]. The designed shape can be reviewed not only by the dental technician who designed it, but also by a dental doctor who uses the dental wire clasp.

In the third step (c), the designed curve is analyzed by an analysis tool which is under development in this study to generate the segmentation of the designed curve as shown in Figure 3(c). Based on the results of analysis [22], a bending operation process is calculated to generate G-code in the fourth step (d), or bending code for the CNC bending machine also under study in this research (Figure 3(d)). The generated G-code is evaluated in simulation model in the fifth step (e) to make sure the feasibility of fabrication as shown in Figure 3(e). The final result of the fabrication in the sixth step (f) is the targeted wire clasp as shown in Figure 3(f).

In order to implement these fabrication processes (a)-(f), design and manufacturing of the CNC wire bending machine as well as the CAM system to control the machine based on the CAD design of wire clasp is under study in this project.

4. A collaborative framework of prosthodontics wire clasp design and fabrication

Computer-assisted collaborative framework of design and manufacturing draws attention in various fields, such as aerospace, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances. While the technologies behind these systems have potentials for industrial applications, they could also be beneficial to the application of digital dentistry. Using the example of laboratory collaboration in the authors' labs, this

section shows it and proposes a collaborative framework for prosthodontics wire clasp design and fabrication based on the idea of CNC wire bending system.
DentLab is located at Kuramoto campus, whereas CELab is located at Josanjima campus which is about 7 km away from Kuramoto. In order to share the large size of data in a timely manner under secure environment, a private cloud server system called CEL-cloud has been installed based on ownCloud program [23] with some customization. A typical usage of this cloud server system is rapid prototyping test samples of prosthetic restoration, which is very beneficial to the lab members. Design data prepared at DentLab is transferred to CELab, where fabrication is processed, then its products are transferred back to DentLab.

Considering the current usage of cloud server system, this research proposes a collaborative framework based on a cyber-physical environment under the collaboration between DentLab and CELab. The framework is composed of private cloud servers which can be accessed by the members of each labs in a secure manner as shown in Figure 4. Data files are stored in these servers, and be shared among the members in a seamless manner with high security along the whole processes of dental wire clasp fabrication. The framework offers a cyber-physical environment to design and manufacture dental wire clasp based on the process flow of CNC dental wire bending system described in the previous section.

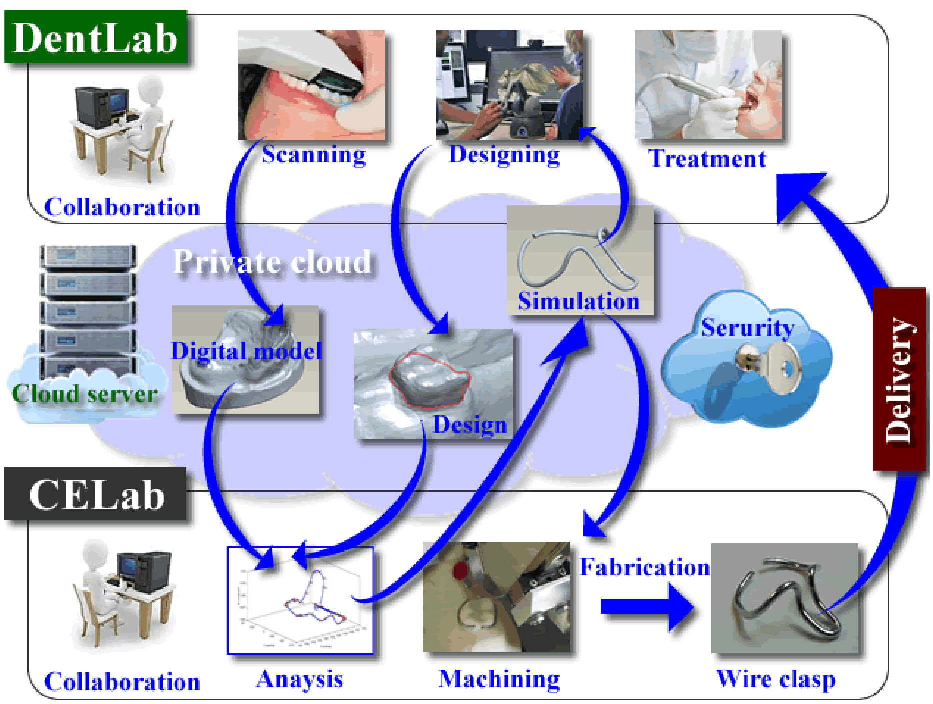

Figure 4. Process flow of cyber-physical dental wire bending system.

5. Concluding remarks

This paper focuses on the two issues in digital dentistry, namely, the integration of collaborative working environment based on the dental CAD/CAM systems and CNC wire bending manufacturing as a new approach of collaboration in digital dentistry.

First, this paper reviewed the dental CAD/CAM system, which is the core for complicated systems in digital dentistry. Integrating with virtual engineering technologies, a cyber-physical dental system based on virtual operation was presented as an example of the extension of dental CAD/CAM system.

CNC wire bending project presented in this paper is one of the application of cyber-physical system for design and manufacturing application. A process flow of CNC dental wire bending system was presented to show how the dental clasp could be manufactured by the CNC wire bending system. Then, the paper proposed a collaboration framework of prosthodontics wire clasp design and fabrication in order to integrate the upstream/downstream activities in dentistry as an approach to the two issues mentioned above.

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Part 8

Decision Support Systems

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Developing an Intelligent Decision Support System to Determine a Stable Flow of Fixtures

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Abstract. The assignment of the right fixtures to their corresponding workpieces and the determination of their stable flows is one of the important challenges for manufacturing systems. This problem has not been well addressed in the past publications. This paper aims to address this problem using an on-demand fixture assignment and control method. A decision support system (DSS) is presented so as to address this problem. This DSS integrates the case-based reasoning (CBR), rule-based reasoning (RBR) and fuzzy set theory components of an artificial intelligence (AI). Cases are represented with an object-oriented (OO) approach in order to characterize them by their feature vectors. A fuzzy weighted Euclidean distance measure is applied for case retrieval. Numerical example is also illustrated to show the applicability of the proposed DSS.

Keywords. Fixture, decision support system, artificial intelligence, case-based reasoning, rule-based reasoning, fuzzy set theory.

Introduction

Among various activities involved in manufacturing processes, fixtures are one of the major problematic components [1]. Fixtures are required to hold, support and locate workpieces for a specific manufacturing operation. They directly affect the quality of products, productivity and cost of products [2-5]. The cost of fixture design and manufacture contributes to 10-20% of the total cost of manufacturing [6]. This cost increases if the available fixtures are not well planned and utilized. Traditionally, fixtures are assigned to workpieces through trial-and-error approaches which are highly resource-consuming. Although the issue of fixture assignment and control is one of the complex problems, this problem has not been well researched in the past as compared to the attention given to fixture design. A wide range of techniques were proposed to make fixture designs more flexible and modular (e.g. see Wang et al. [5] and Boyle et al. [1]). Research findings in fixture assignment and control so as to improve the utilization of such fixtures are limited. This paper presents a DSS which supports decision-makers to undertake on-demand fixture retrieval, supply and manufacture. It determines a stable flow of fixtures within a specific production period. This avoids the unnecessary congestion of fixtures and production downtime due to their shortages.

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The remainder of this paper is organized as follows: section 1 briefly discusses the integrated performance of CBR, RBR and fuzzy set theory in decision-making. Section 2 describes the proposed DSS in terms of case representation, case retrieval and fuzzy decision-making. In section 3, numerical example is illustrated. Finally, conclusions and suggestion for future research are forwarded in section 4.

1. Artificial intelligence and DSS

This section describes the integrated applications of artificial intelligence (AI) components, namely, CBR, RBR and fuzzy set theory. RBR uses domain knowledge from well-defined theory as rules to infer about new problems, while CBR draws inferences of a new problem based on experiences learned from the previously encountered cases [7]. Many real-life problems occur between these two extreme ends. Combining RBR and CBR are popular strategies to be benefited from their synergic effects in reality [7-12]. According to Aamodt and Plaza [10], a general CBR cycle is presented by four processes named retrieve, reuse, revise and retain (Figure 1). Retrieve is searching the most similar historical case that matches to a new case using predefined similarity measures. If the retrieved case is strongly similar to the new problem, reuse will be the best solution. If the retrieved case does not match to the new case, it undergoes a revision so as to adapt to the new problem. The adapted solution is tested and verified, the confirmed solution is retained with its corresponding problem as the learned case for the future reuse and adaptation.

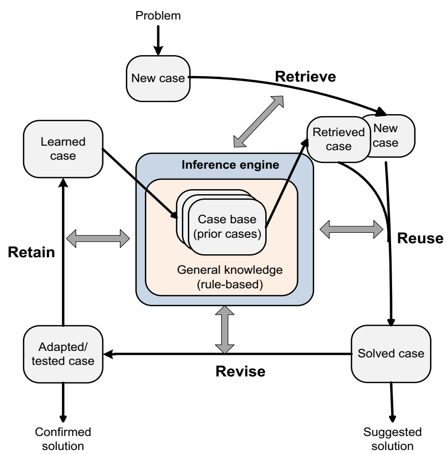

Figure 1. CBR cycle integrated with RBR (adopted from [10]).

Fuzzy set is useful to grade the degree of membership of objects in imprecise, vague and uncertain environment [13]. It is usually used to solve problems in which their descriptions are imprecise and vague to clearly define their boundaries. In the real situation, various decisions are made in an environment in which the goals the constraints and the consequences of possible actions are not known precisely [14]. In situations in which an integrated application of CBR and RBR is required, the rules in decision-making are imprecisely described in terms of linguistic terms such as strong similarity, weak similarity, etc. so as to define the level of similarities among the new and prior cases. Besides, rating the importance of attributes is purely subjective and vague. In addition, some attributes of objects can be well expressed with verbal terms rather than crisp values.

2. Description of the DSS

Figure 2 presents the decision logic of the proposed DSS. The manufacturing environment is assumed to be dynamic but deterministic within a specific manufacturing-window period. Suppose *m*-parts are scheduled to be manufactured, the DSS is intended to determine *n*-stable number of fixtures required to process these *m*-products at a given workstation. Assuming similar parts require the same fixture, different attributes of parts, including their corresponding importance rates (weights), which can characterize their similarities for fixture assignment, are determined.

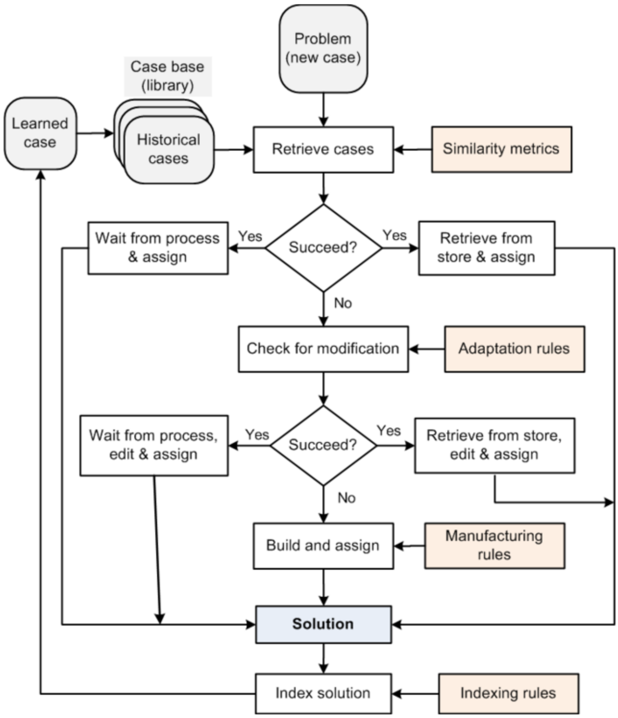

Figure 2. Decision logic for on-demand fixture retrieval and manufacture.

Different rules are developed in order to simplify the case representation and retrieval, and decision-making. Cases are represented using an object-oriented (OO) technique in the Java programming language. The DSS supports users to reuse or adapt or manufacture a new fixture after a case retrieval based on the similarity measure between two neighboring cases. It consists of two types of case libraries: (1) for new cases which need a new fixture to be manufactured; (2) for new cases which reuse or adapt the past cases. When a new fixture is required for the new case, this new case with its assigned new fixture serves as a new training sample for the future retrieval, reuse and adaptation. However, when the new case reuses or adapts the prior case, no need of adding it into the training samples because that past case is working as one of the members of training samples.

2.1 Case representation

A case can be either a new problem or a training sample. The training samples are considered as the historical problems with their corresponding solutions. In Figure 2, the new problem represents a part-order arrival with a complete description of its attributes from the database. It incorporates physical features of the workpiece (e.g. shape, size, surface roughness, etc.); functional features (e.g. tolerance limit, material type, etc.); the types operations required at a given workstation (e.g. internal machining, external machining, etc.). These attributes are used to represent the cases in n-dimensional Euclidean vector space. The cases are represented with the help of an OO approach because of its structured and compact-data representing capability and software reusability [15]. The case representation in this DSS is highly comprehensive and flexible. It incorporates the attributes which are expressed with continuous and discrete numerical values, nominal values of {0, 1}, and either crisp or fuzzy scores. It converts descriptive or symbolic attributes into nominal values of {0, 1}.

All the numerical values of the attributes are normalized into membership values within a range of [0, 1]. This normalization is useful to unify mixed numerical, nominal and symbolic values of feature vectors, and to avoid the influences of measurement unit and scale changes. Equation (1) is applied to calculate the normalized values of feature vectors [16].

Table 1. Case representation matrix .

	w_1	w_2	. . .	w_n
	$\mathbf{A}_1$	$\mathbf{A}_2$	. . .	$\mathbf{A}_n$
$\mathbf{P}_1$	a_{11}	a_{12}	. . .	a_{1n}
$\mathbf{P}_2$	a_{21}	a_{22}	. . .	a_{2n}
.	.	.	. . .	.
.	.	.	. . .	.
.	.	.	. . .	.
$\mathbf{P}_m$	a_{m1}	a_{m2}	. . .	a_{mn}

Where

m is the total number of parts planned to be manufactured.

n is the total number of attributes in n-dimensional Euclidean space vector.

$\mathbf{P}_1\ldots\mathbf{P}_m$ are m-finite parts planned in a given order arrival sequence.

$\mathbf{A}_1\ldots\mathbf{A}_n$ are n-finite attributes to characterize each part-order.

a_{ij} is the normalized feature vector value of the part-order $\mathbf{P}_i(i=1\ldots m)$ against the attribute $\mathbf{A}_j\,(j=1\ldots n)$.

$w_1\ldots w_m$ are normalized weights assigned to attributes.

$$a_{ij} = \frac{x_{ij}-x_{imin}}{x_{imax}-x_{imin}} \quad (1)$$

Where

x_{ij} is the real feature vector value of a_{ij}, which is not normalized.

x_{imin} and x_{imax} are the minimum and maximum value of the jth attribute among m-part-orders respectively.

2.2 Rating the importance of attributes

Weights for attributes are allocated using fuzzy simple additive weighting (FSAW) technique. This method is selected for this paper because of its simplicity and popularity, but there is no restriction to use other approaches. The weights of attributes are rated in terms of linguistic terms like “very high”, “high”, etc. to depict the importance of attributes. Importance ratings are purely subjective and vague so as to define their boundaries. The linguistic terms are first converted into their equivalent fuzzy numbers and then the fuzzy numbers are transformed into their corresponding crisp scores by adopting a fuzzy ranking approach proposed by Chen and Hwang [17]. This method is applied in the proposed DSS because of its simplicity, comprehensiveness and flexibility. The conversion of linguistic terms into their corresponding trapezoidal and triangular fuzzy numbers is indicated in Figure 3 (x is any real number in [0, 1] and $\mu(x)$ is the degree of membership of x to the linguistic terms). In this figure, verbal terms of triangular numbers are used but it can be extended to create several trapezoidal fuzzy numbers by combining two neighboring triangular fuzzy numbers. For example, a trapezoidal fuzzy number (0.6, 0.7, 0.8, 0.9) can be created by combing Fairly high (0.6, 0.7, 0.8) to High (0.7, 0.8, 0.9).

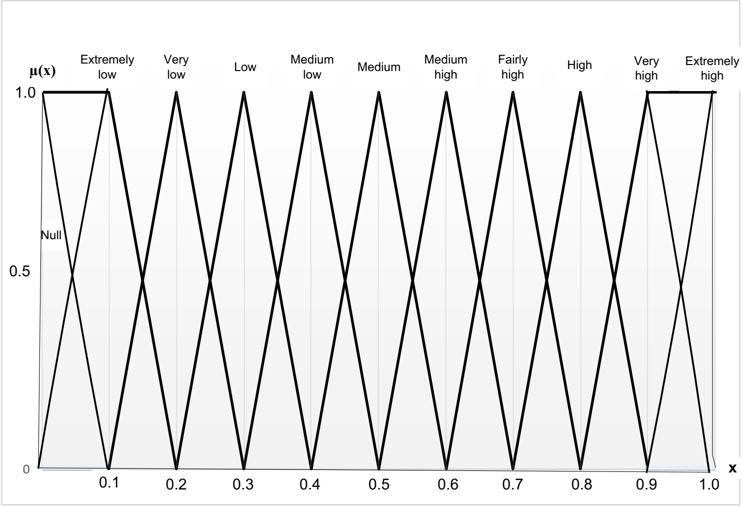

Figure 3. Conversion of linguistic terms into fuzzy numbers.

The fuzzy numbers converted into their corresponding crisp scores with the help of the left and right scores of a fuzzy number. The right and left scores can be determined using maximizing and minimizing sets (Figure 4):

$$\mu_{max}(x) = \begin{cases} x, & 0 \leq x \leq 1 \\ 0, & otherwise \end{cases} \tag{2}$$

$$\mu_{min}(x) = \begin{cases} 1 - x, & 0 \leq x \leq 1 \\ 0, & otherwise \end{cases} \tag{3}$$

Because the fuzzy numbers considered in this paper are continuous, convex, and normal, the right score, R_s, can be determined by taking the intersection of the right leg of the fuzzy number and $\mu_{max}(x)$. Similarly, the left score, L_s, is the intersection of the left leg the fuzzy number and $\mu_{min}(x)$. The total score, T_s, of any fuzzy number (FN) can be computed as follows:

$$T_s = (R_s + 1 - L_s)/2 \tag{4}$$

The fuzzy number with a higher total score is considered better.

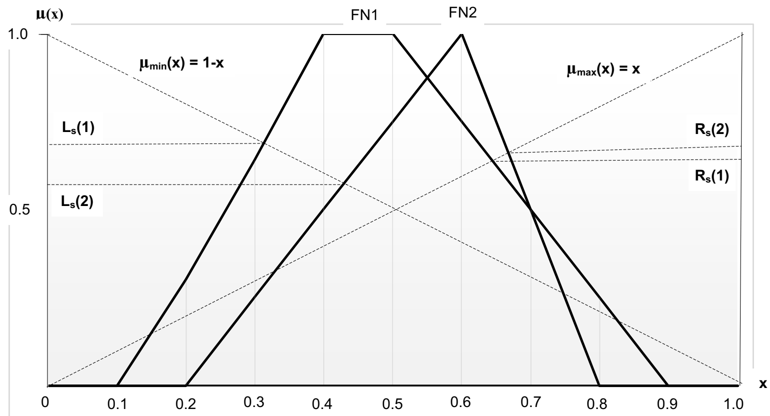

Figure 4. Fuzzy number ranking using the left and right scores.

2.3 Case retrieval

The proposed DSS in this paper uses one of the popular nearest neighbor (NN) similarity measurement techniques in high dimensional vector spaces, which is called the inverse of weighted Euclidean distance. Euclidean distance measures the distance between objects based on the location of objects in Euclidean space [15, 18]. From this weighted Euclidean distance, the similarity between the new case and each training sample is determined. The weighted Euclidean distance between two *n*-dimensional vectors of any two part orders k and *l*, $d_e(k,l)$, is calculated as below (from Table 1):

$$d_e(k,l) = \left[\sum_{j=1}^{n} w_j^2 (a_{lj} - a_{kj})^2\right]^{1/2} \tag{5}$$

The values of $(a_{lj} - a_{kj})^2$ are in [0,1]. The maximum distance, $d_{e,max}(k,l)$ is obtained when all the values of $(a_{lj} - a_{kj})^2 = 1$, and the minimum distance, $d_{e,min}(k,l)$ occurs when all the values of $(a_{lj} - a_{kj})^2 = 0$ (i.e. $k=l$ and $d_{e,min}(k,l) = 0$).

$$d_{e,max}(k,l) = \left[\sum_{j=1}^{n} w_j^2\right]^{1/2} \tag{6}$$

The similarity or closeness between any two part orders k and *l*, $sim(k,l)$, can be determined as follows [18]:

$$sim(k,l) = 1 - d_e(k,l) \tag{7}$$

Distance and similarity are inversely related. The minimum similarity, $sim_{min}(k,l)$, is:

$$sim_{min}(k,l) = 1 - d_{e,max}(k,l) \quad (8)$$

The maximum similarity, $sim_{max}(k,l) = 1$, i.e. $(1 - d_{e,min}(k,l) = 1 - 0)$. Then $sim(k,l)$ falls in $[sim_{min}(k,l),\ 1]$. A historical case with a higher similarity value must be preferred.

2.4 Proposal of decisions

After the case retrieval, the next step is proposing a set of decisions depending on the calculated values of similarity measures. The major decisions are to reuse or adapt the retrieved fixture or manufacture a new fixture. The rules of decision are:

- If the similarity value is close to one (the upper limit), the decision is to reuse the retrieved case.
- If the similarity value is medium, the decision is to adapt the retrieved case.
- If the similarity value is near to the minimum value (the lower limit), the decision is to manufacture a new fixture.

The rules to implement these decisions are imprecise and vague. The similarity levels can be expressed with linguistic terms such as high, medium and low. The relationships between such linguistic terms and similarity measures are indicated in Figure 5. The variable x represents the similarity measures in [0, 1] and $\mu(x)$ is the degree of membership of x to the linguistic terms such low, medium and high similarities.

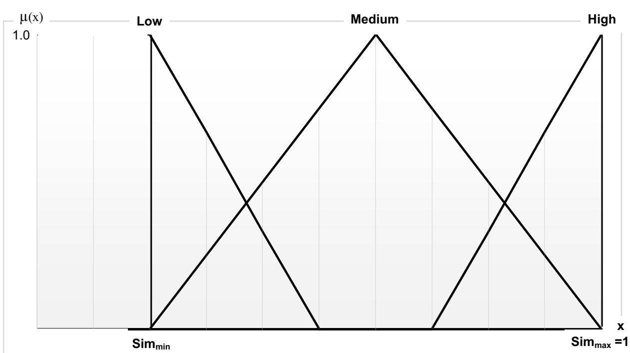

Figure 5. Relationship between similarity values and linguistic terms.

Finding the intersection of the left leg of High and the right leg of Medium, the similarity level to terminate reusing and start adaptation of the retrieved case can be determined. In the same way, using the intersection of the left leg of Medium and the right leg of Low, the similarity level to terminate adaption of the retrieved and start manufacturing a new fixture can be found.

When the decision to reuse or adapt is passed, the DSS checks the available of the required fixture in the database (store). If it is available then the fixture should be retrieved from the database and assigned to the new part-order arrival. Else it should be in the process and the part-order should wait the item from the process. Finally, every case should be indexed in its case library. Indexing is useful to give an identification label to the current assignment decision with its corresponding problem for the future retrieval, reuse and adaptation [12].

3. Illustrative numerical example

The numerical example is illustrated in a laboratory environment to make it more understandable and simplified. A milling operation, which is one of the basic machining operations, is considered. Its aim is to assign and control the milling vises (fixtures). Eight attributes of the parts to be machined are taken into consideration. Table 2 indicates these attributes incorporating their importance rates in terms of linguistic variables, their corresponding fuzzy numbers, crisp scores, and normalized weights (refer to Figure 3, Figure 4, and Equations (2) - (4)).

Table 2. Attributes and their corresponding weights.

Attributes	Importance (verbal)	Fuzzy number	Crisp score	Weight (w_j)
Shape	Very high	(0.8, 0.9, 1.0)	0.864	0.156
Material	Fairly high	(0.6, 0.7, 0.8)	0.682	0.123
Length	High	(0.7, 0.8, 0.9)	0.773	0.139
Width(diameter)	High	(0.7, 0.8, 0.9)	0.773	0.139
Surface finish	Medium high	(0.5, 0.6, 0.7)	0.591	0.107
Tolerance	Medium	(0.4, 0.5, 0.6)	0.500	0.090
External milling	Fairly high	(0.6, 0.7, 0.8)	0.682	0.123
Internal milling	Fairly high	(0.6, 0.7, 0.8)	0.682	0.123

Shape and material type are descriptive attributes which are converted into nominal values of {0, 1} using the rules developed in the DSS. For example, if the shape of the new case and past case are identical, similarity value is one, else it is zero. The same works to material type. Alternatively, these attributes can be represented with linguistic terms. For example, the machinability of the material type can be described in terms verbal terms such as “high”, “medium”, “low”, etc. and then the linguistic terms should be converted into crisp scores using Equations (2) - (4). Length, width, surface finish and tolerance are represented with continuous numerical values and transformed into values of [0, 1] using Equation (1). External milling and internal milling are operational requirements, which are represented with nominal values of {0, 1}. For instance, if the part needs external milling operations such as facing, chamfering, etc., its value for this attribute is one, otherwise it is zero. The same is applied for internal milling. Table 3 indicates eight parts (new cases) including their feature vector values, which are planned to be manufactured in a given short period. Table 4 shows two training samples (TS) which are initially acting as the past cases.

Table 3. Part orders (new cases) with their attribute values.

Part	Shape	Material	Length	Width	Surface	Tolerance	Ext. Mil.	Int. Mil.
P1	Solid prism	Aluminium	0.36	0.65	0.47	1.00	0	1
P2	Solid cylinder	Cast iron	0.77	1.00	0.00	0.43	1	0
P3	Hollow cylinder	Stainless steel	0.51	0.47	1.00	0.57	0	1
P4	Hollow prism	Aluminium	1.00	0.82	0.47	0.29	0	1
P5	Hollow cylinder	Stainless steel	0.48	0.52	0.97	0.00	0	1
P6	Solid cylinder	Alloy steel	0.91	0.00	0.56	0.10	1	0
P7	Solid prism	Carbon steel	0.00	0.95	0.12	0.92	1	1
P8	Hollow cylinder	Cast iron	0.53	0.48	0.64	0.52	0	1

Table 4. Training samples (past cases with assigned fixture).

TS	Shape	Material	Length	Width	Surface	Tolerance	Ext. mil.	Int. mil.	Fixture assigned
TS1	Solid cylinder	Alloy steel	0.96	0.23	0.54	0.06	1	0	fix12
TS2	Solid Prism	Carbon steel	0.04	0.95	0.01	0.98	1	1	fix07

The similarity between the new cases and training samples is calculated using Equations (5) and (6). The minimum similarity value, sim_{min} = 0.64, from Equation (8). The minimum similarity values to reuse and adapt the retrieved cases are computed to be 0.91 and 0.73 respectively, referring to Figure 5. The following summarized results are determined with the help of the proposed DSS.

Table 5. Summarized results of the proposed DSS.

New case arrived	Nearest past case	Similarity value	Proposed Decision	Proposed fixture	No. fixtures in the system
P1	TS2	0.81	Adapt	fix07	2
P2	TS1	0.82	Adapt	fix12	2
P3	TS2	0.72	Manufacture	New (fix16)	3
P4	P3	0.78	Adapt	fix16	3
P5	P3	0.95	Reuse	fix16	3
P6	TS1	0.97	Reuse	fix12	3
P7	TS2	0.99	Reuse	fix07	3
P8	P3	0.87	Adapt	Fix16	3

The above table shows that three fixtures are required to machine all the product-orders. Initially two fixtures are considered using two training samples. As P3 is arrived, the existing training samples are unable to machine it (adaptation is impossible) and a new fixture is required to be manufactured and assigned. This new case is considered as a new training sample for future retrieval, reuse and adaptation. This is happened when P4 and P5 are arrived at the new cases. P3 is added into the first case library which consists of training samples. This case library is the one which determines the number of active fixtures in the system for a given operation i.e. the number of cases in this library equals to the number of functional fixtures in the system. The remaining seven cases are placed in the second case library which contains the cases which are utilizing the retrieved cases from the first library.

4. Conclusions and suggestions for future research

In the real manufacturing situation, product mix variation is very high and a huge number of fixtures are required. Systematic fixture assignment and control technique is required to determine the stable number fixtures in advance. The DSS presented in this paper is a promising approach to utilize the existing resources based on demand-driven decisions. Fixtures must be retrieved or manufactured and supplied to the system when they are only required. In this paper, an integrated performance of CBR, RBR and fuzzy set theory has been revealed to retrieve, reuse, adapt the past cases in the case library and build new fixtures based on the guiding rules from RBR. The proposed DSS is capable to process attributes and their weights represented with continuous and discrete numerical values, nominal values, descriptive/symbolic values and fuzzy linguistic terms. This kind of unified representation is useful for the DSS to process imprecise, vague and uncertain information as similar as human thinking and decision-making. Although the numerical example has been illustrated using limited number of new cases and training samples, the DSS is capable to address any number of parts scheduled, training samples and feature attributes. It can also be implemented to decision-based tools and jigs assignment problems. This implies that this DSS is highly flexible for future adaption and innovation.

In the future, the real industrial systems will be considered rather laboratory environments. Besides, the performance of the proposed DSS will be tested and validated with help of discrete-event simulation (DES) software packages. If the required performance is achieved, the proposed solution will be accepted and implemented. Otherwise, the DSS should propose another improved solution for the DES. Such kinds of activities will be undertaken by combining the DSS and DES models. In addition, the issues of permanent adaptation and removal of inefficient fixture are suggested to be addressed to make the system more practical.

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A Framework for Interoperability Assessment in Crisis Management

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Abstract. It is noticeable the growing of the various types of concerns in large centers, whether by citizens or public officials. In that sense, an important dimension is the crises management such as in cases of natural disasters. This scenario calls for a task force in an attempt to predict or solve emergencies, especially in managing and integrating public and private spheres, which in turn are centered on public authorities, service providers, citizens, volunteers and systems. In order to allow the exchange of information and joint actions of those involved entities, the fulfillment of interoperability requirements become a critical factor promoting improved performance of the actions taken in situations of crisis. Based on the literature and related worldwide initiatives, the main concerns and attributes of crisis management are identified from the perspective of interoperability. Founded on this knowledge a framework that supports a Disaster Response Management System (DRMS) development cycle is proposed. In this paper, a focus is done on a diagnostic step based on a Multi-criteria decision analysis (MCDA) in order to assess potential interoperability of a public entity or locality. The proposed MCDA method facilitates the specification of integrated solutions for the public sector to meet interoperability requirements in disaster management scenarios.

Keywords. Disaster management system, interoperability assessment, disaster response, multi-criteria decision analysis.

Introduction

A crisis situation can occur in different ways, such as political, military, economic, humanitarian, social, technological, environmental or health. Lately is notable that the authorities are increasingly seeking solutions to improve the management of crises. Part of this growth is due to increased citizen participation, both in collaboration in crisis moments and in monitoring the measures taken by the responsible [1].

Regardless of its nature, it is possible to consider that the crisis is an abnormal situation, usually resulting from an instability that brings impact to a particular segment with unacceptable consequences. This implies the need for crisis management, which involves the participation of various entities working together in a life cycle based on four main phases: mitigation, preparedness, response and recovery [2]. The response dimensions represent the most relevant stage in order to meet performance requirement

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in crisis management. The related efficiency is determined by the speed and precision with which information can be managed and exchanged between the partners (i.e., organizations, people, and devices involved in the collaboration). Thus, a successful crisis management requires the full integration of all involved, especially in response actions [1].

It is possible analyze a crisis management scenario considering two important entities directly involved in this kind of unexpected situation - firefighters and police. In the case of a notification, for instance, of a large crash on a highway, information simultaneously arrives at more than one police or fire departments without proper control and information sharing. This disaster event thus results more than one rescuer team sent to the scene and a impair mobility due to concentration of rescue vehicles. The resulting no-interoperable scenario highlights the importance of information exchange and integration of the different services involved in an incident.

Interoperability can be defined as a broad concept encompassing the ability of organizations to work together in pursuit of common goals and mutually beneficial. Thus, if two or more systems do not have the ability to collaborate, exchange information and coordinate actions, they cannot be considered interoperable in its domains [3]. For entities become interoperable, they must meet certain common goals and requirements, which in turn must be set according to each area or domain. To identify their capabilities, the entities should be subject to an assessment, which allows stressing out how a particular organization is interoperable in its domain to face disaster scenario.

This paper presents a DRMS development cycle framework with a focus on a diagnosis step devoted to potential interoperability assessment of a public/private entity or locality. The proposed approach is based on a multi-criteria decision analysis structure based on AHP (Analytic Hierarchy Process) and helps the organizations to perceive their strengths and weaknesses, encompassing actions to increase performance and maturity, closely related to their ICT capabilities. The diagnosis results support the specification of a DRMS in order to fulfill interoperability requirements coherent to entity capabilities on disaster management.

1. Scientific scenario and related works

1.1. Disaster Management

There are three main aspects of disaster management - life protection, property and the environment. Most often disasters are classified mainly into natural and man-caused categories. The former is related to events such as earthquakes, floods, storms, hurricanes, tornadoes, cyclones and forest fires. The latter, called man-caused, covers events such as fire and collapse of buildings and airplane accidents. Regardless of the type of disaster mitigation, an effective and coordinated action is a difficult task to the first responders [4].

The various rescue organizations such as police, fire, health, civil defense and other organizations need to be efficient when working in a collaborative way, considering the inter and intra organizational aspects, in addition to the different hierarchical levels of each involved team [5]. Thus the exchange of information becomes an essential prerequisite for dealing with the various types of disaster in a rapid and coordinated manner. To allow the exchange of information aiming the prevention or mitigation of crisis situations a proper management and integration of its participants is needed [1]. Thus the whole operation requires that the information is up to date as possible, requiring real-time communication between participants.

This real-time exchange calls for the need to characterize information and communication technology system (ICT) integrated in disaster management, making the exchange and processing efficiently and safely [5]. Most collaboration issues and communication of a company are supported by Information System (IS) without capabilities to face process coordination and information flow between heterogeneous entities and systems. The implementation of a Mediation Information System (MIS) supported by Service Oriented Architecture (SOA), represents an interesting solution allowing an evolutionary monitoring of the crisis scenario and the management of information between involved entities [6].

Thus, in the field of emergency and disaster, the Crisis Information Management Systems (CIMS) or Disaster Management Interoperability System (DMIS) has been part of the prevailing concept in use in real cases as proposed in [7] [8]. Its main objective is to provide a complete set of ICT functions to address many needs of the actors in crisis management. CIMS has been highlighted as a preferred system of entities to meet the main needs of a crisis, especially in the exchange of information, enabling a joint and coordinated actions of those involved efficiently [7]. Some actions performed by these types of systems [9]: conduct an assessment throughout the period of crisis; start, maintain and control communications; identifies the incident management strategy; makes decisions according to the found resources; request additional resources; develop an organizational command structure; continually review action plans; provide continuation, transfer and termination of a call.

Therefore it is noticeable that the crisis management occurs efficiently when the information is exchanged and updated in real time between the involved organizations. These requirements suggest the use of technological tools to control and manage the data according to each occurrence [5]. Most often the speed and precision with which information can be managed and exchanged between the partners (organizations, people, and devices involved in cooperation) contributes with the results in the efficiency level of response [1].

But this is not the only important part to allow the operation of entities. It is necessary for organizations to adopt some established norms and standards for its domain, contributing to the interoperation of activities. It is essential that the business aspects of the organization, such as processes and business are aligned with the established standard, given syntactic and semantic requirements. The rules for the sector already consider cultural, legislative, different practices and various other factors that may contribute to loss of organizational interoperation [11].

With the necessity for better integration and management, organizations are also concerned about the quality of their participation in the acting domain. The entities are seeking to evaluate their interoperation capacity, aiming to better performance of the organization and also contributing to a more efficient environment [10]. The assessment of interoperability of a company is crucial to identify its weaknesses. When it comes to activities related to crisis management, each improvement can be even more important, since the domain is directly linked to emergencies involving risk to citizens. With the weaknesses identified, the activities can be improved and risks reduced, contributing to the efficiency of the process. Evaluations can be performed in comparison with another entity (a posteriori) or a generic domain (a priori) [13].

Among the phases of crisis management, the response step is the most important one because this phase does not allow errors. It requires coordinated and efficient actions, which is even more difficult with the participation of several entities. The interoperability aspects and their assessments contribute to the success of these activities [10].

1.2. Interoperability

The interoperability is considered progressive when organizations start to communicate and share information, and together create performance conditions that would be hard to achieve individually [14]. Going beyond people, machines and systems, interoperability is becoming a key success factor in all areas. The concept of interoperable systems therefore requires considerable attention to be evaluated and continuously improved [11]. A broad concept, encompassing the ability of organizations to work together in pursuit of common and mutually beneficial goals, represents one of the definitions involving interoperability [12]. This ability to interoperate can be affected by conceptual, technological and organizational barriers, which are classified [13]: Conceptual concerning different ways to represent and communicate concepts; Technological relating incompatibility of data and systems; Organizational regarding different methods of work.

The Enterprise Interoperability Assessment (EIA) allows the measurement of the degree of interoperation between entities, which in turn helps the specification of integrated solutions in the domain as well as the adjustment and adaption to improve the activities of those involved [11]. This type of evaluation identifies strengths and weaknesses imposed by interoperability barriers, enabling the prioritization of actions in order to enhance interoperability performance and maturity.

The literature presents several methods and models of assessment [15]. Evaluations can be based on Interoperability Maturity Models (IMMs) in order to infer about the potential degree of interoperation [16]. Each assessment approach should be conducted according to the domain to be assessed and may require a brief survey to identify the attributes and criteria that best characterizes the domain through interoperability perspectives [17]. In the context of this paper the assessment approach relies on the use of interoperability concepts in order to evaluate the entity coverage level within the crisis management domain, thereby allowing the identification of possible adjustments in order to improve disaster response performance.

The need to interoperate in crisis management activities determines the way that operations and service occur. The responsibilities involved in this scenario can be divided into state, national or even international spheres, represented by different teams from different public or private entities as civil defense, firefighters, police, etc. According to [10], entities mainly involved in crisis management should work through a life cycle consisting of phases: prevention, preparation, response and recovery. The authors seek to identify relationships through each stage of the crisis process, allowing the improvement of inefficient points and improved performance of Disaster Management Organizations (DMOs). In [18] the authors advocate that the analysis and search for interoperability requirements are focused on integrating lifecycle approach using the Enterprise Architecture approach (EA).

The new advent of Internet-of-Things (IoT) brings increasing complexity and diversification in information systems, making interoperability a key requirement for its scalability and sustainable development. In crisis management context [19] the situation is different because the process involves most of the time a very heterogeneous group of entities that must work together in providing services and responses. In this case, ontology is used to identify and relate the various types of agreements between organizations, thus helping to create a unique environment that can be communicated through the same pattern, leading to the concept of Interoperability-of-Everything (IOE).

1.3. Worldwide Initiatives

The survey of the initiatives within the crisis management domain collaborates with the identification of best practices and technical requirements that can support a Disaster Response Management System (DRMS) development cycle. These systems are characterized as DMS (Disaster Management System) and mainly focused on the response to a particular occurrence. Some successful worldwide initiatives are presented next. They collaborated with the identification of relevant attributes concerning disaster management scenario assessment, as well as to support a relational study between these attributes and ICT interoperable requirements.

SAFETRIP [20] - Satellite application for emergency handling, traffic alerts, road safety and incident prevention (France)

Currently it has been noticed an increase in research and development of systems to assist the driver. Such systems are based on automated technologies and sensors capable of detecting the traffic situation around the vehicle warning the driver or performing some mechanical action automatically. In addition to vehicles, roads have also received significant improvements. Intelligent communications systems that interact with many devices and vehicles are being deployed with good results [20]. In this way, the SAFETRIP is one of these intelligent systems designed to improve the use of the road transport infrastructure generating alerts with many degrees of importance: informative, preventive, promoting actions, etc. This system helps to reduce the number of accidents and deaths because it increases the mobility of the involved entities and the information distribution. Vehicles can be interconnected via different media (called ICT) such as telephone channels, satellite and WiFi, radio, etc. To improve the exchange of information, new satellite technologies are being implemented to improve the communication in extreme environments and other problematic situation [20].

DECIDE [21] - Decision Support System for Disaster Emergency Management (Greece)

This project aims to provide assistance during emergencies caused by natural agents or by human action. It aims to improve the capacity of involved resources and also preventing future occurrences. Its development was motivated by the high complexity of the actions necessary to during disaster situations. A quick response and the prevention plans development are difficult because of this complexity. To minimize such difficulties, DECIDE proposes an Intelligent Decision Support System (IDSS) to promote greater efficiency and management capacity of local responsible and stakeholders to respond effectively to all types of disasters. The system proposes some goals, encouraging the use of innovative solutions and technology base to increase the capacity of local authorities to achieve effective and efficient coordination in the prevention and response procedures. These procedures should consider the risks and enhance the capacity of society and volunteers to support a local disaster control, thus avoiding further losses. The main ways of achieving the goals is through IDDS where you can see its main features below:

- allocation of civil protection units;
- routing and guidance in emergency situations;
- network based on geographic information system (GIS) and risk mapping;
- viewer roles and responsibilities;
- alerts and warnings;
- management scenarios and users;
- multiple end user interfaces support (web, phone etc.).

SAVE ME [22] - System and Actions for Vehicles and transportation hubs to support Disaster Mitigation and Evacuation (United Kingdom)

In recent years, a large number of people have died due to natural disasters, fires in tunnels and public transport terminals. In addition, governments still have the difficult task of dealing with the threat of terrorist attacks. Synthetic or natural disasters always require rapid and coordinated response taking often mass evacuation scenarios. SAVE ME project aims to prevent these disasters by developing systems that detect both types of events. The system must support mass evacuation policies in a very short time protecting the lives of all involved. The system also provides features to handle all kinds of people, including people with some disability [22]. To achieve its objectives, the project presents an ontological framework able to recognize the different types of threats, classify them and propose possible solutions for their reduction. The approach is founded on a complex and innovative algorithm based on human behavior (under stress, panic and strong emotions, etc.). These behaviors can indicate an abnormality working as trigger alerts to be send to the respective responsibles.

2. DRMS development cycle framework

The proposed DRMS development cycle framework shown in Figure 1 aims to provide the organization the opportunity to discover and evaluate its strengths and weaknesses, facilitating the prioritization of actions to improve its performance and maturity. The idea of the proposal is to use the concepts found along with the aspects that directly reflect the domain interoperability issues to achieve disaster response management (DRM) objectives.

The proposed framework is centered on Disaster Response Interoperability Assessment Model (DRIAM), which aims to evaluate a reference DRMS architecture according to aspects of interoperability. The diagnosis promoted by DRIAM allows a granular assessment of capabilities of a public or private entity involved in DRM. As a result of this capabilities analysis, a deeper relational review of the functional and technical requirements of the reference architecture with DRM attributes could be conducted. The main steps and components of the framework are shown in Figure 1.

The process begins by creating the knowledge base in disaster management domain represented by a set of attributes. The knowledge could be obtained from various sources, such succeeded initiatives, literature review and consultations with experts. The attributes are divided into two forms: (i) the so-called domain attributes (DA), which its main source is focused on the extraction of literature and disaster management specialists; (ii) technical and functional requirements, or simply system requirements (SR), identified from existing DMRS initiatives and also expert knowledge.

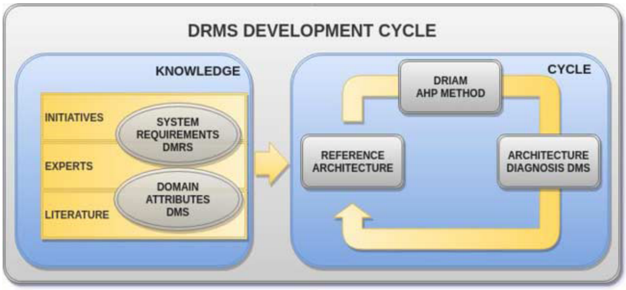

Figure 1. DRMS development cycle framework.

The first data set (domain attributes - DA) consists primarily of needs found within the crisis management domain, such as connectivity, safety, flexibility, among others. The second set of information (system requirements - SR) allow to identify the necessary means to ensure that the domain attributes (DA) are supported, for example the band speed, proxy settings and tools for system adaptation. Use cases could also be included in the system analysis and are normally presented directly by the involved stakeholders. Both the DA domain attributes as the system requirements must meet the interoperability requirements (I).

The scheme presented in Figure 2 illustrates, through a tridimensional view (cube), the relationship between the mentioned perspectives (DA, SR and I). The relational analysis that emerges from which perspective (cube surface) is conducted by DRIM (Disaster Response Interoperability Matrix) inspired in QFD (Quality Function Deployment) [23] and Axiomatic Design [24] methods. The DRIM will support the design of the DRIAM assessment structure based on AHP method. A similar approach is proposed in [25] concerning e-gov attributes and interoperability perspectives.

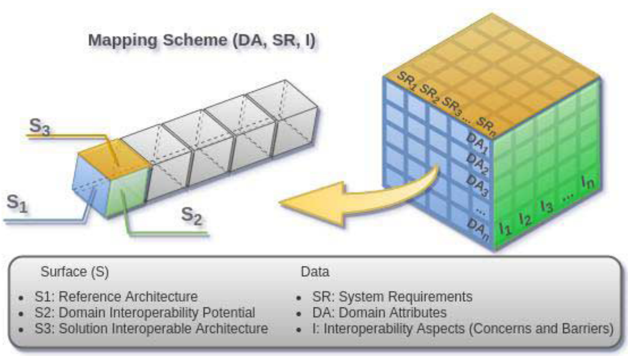

Figure 2. Mapping through the cube components.

Related to S1 surface (Figure 2), the purpose of the DRIM construction is to identify how the DRM needs are covered by the technical requirements. With this matrix is possible to calculate how the technical requirements (SR) should be improved to meet the DRM requirements (DA). These importance levels could be applied by specialists, through brainstorms, use cases study, DEMATEL method [26], etc. The crossing of data conducted by DRIM is illustrated in Table 1, showing the degree of importance of each domain attribute (DA) to the system requirement (SR).

Table 1. Reference Architecture (S1).

Domain Attributes (DA) \ System Requirements (SR)	Importance	Modular Approach	Uniform Emergency Signals (Alerts)	Relational Data Model	Open SQL data Language	Multiple Data Formats	…
Able to be connected on old systems	3	1	9	3	9	9	
Data sharing	9	3	9	3	9	9	
Able to interoperate with other architectures	9	3	9	3	9	9	
Work with different type of crisis	3	3	9	3	9	9	
Agile (good Performance and flexibility)	9	3	3	9	9	9	
Easy to include new modules	9	9	9	9	9	9	
Not Complex Systems	3	3	9	9	9	3	
Aceptable for Governamental Services	3	9	9	1	9	9	
Depiction (Physical Representation in a digital format of the environment)	3	0	1	3	3	9	
⋮							

Concerning the surface S2, the Table 2 concerns the DRIM analysis between DA and interoperability (I) concerns. The aim of this relational analysis is to bring to the interoperability perspectives (I) the assessment of disaster management attributes (DA) fulfillment. This DRIM acts as a basis for AHP structure design (DRIAM) shown in Figure 3. The first level corresponds to the goal of the AHP method. The second and third level represent the evaluation criteria, with the Interoperability Perspectives (I) and Domain Attributes (DA). The fourth and final level is the potential interoperability assessment.

Table 2. DRIAM QFD Method (S2).

Domain Attributes (DA) \ System Requirements (SR)	Business	Process	Service	Data
Able to be connected on old systems	0	1	9	3
Data sharing	1	1	9	9
Able to interoperate with other architectures	0	1	9	3
Work with different type of crisis	9	3	1	1
Agile (good Performance and flexibility)	1	9	3	1
Easy to include new modules	3	9	3	3
Not Complex Systems	3	9	1	1
Aceptable for Governamental Services	9	3	3	1
Depiction (Physical Representation in a digital format of the environment)	3	1	3	1
⋮				

Through AHP method and DRIAM, a diagnosis of the private or public entity capabilities, on each DA and under I perspectives, is carried out. As a result, the potential interoperability of the entity is assessed in order to infer about its capabilities on disaster response management and the supporting of the referential DRMS architecture review (coherent to its capabilities).

Finally, the third face of the cube (S3) shows a diagnostic perspective on the system requirements (SR) with aspects of interoperability (I). This analysis step will contribute to the review of the referential architecture specification, in order to meet system interoperability requirements.

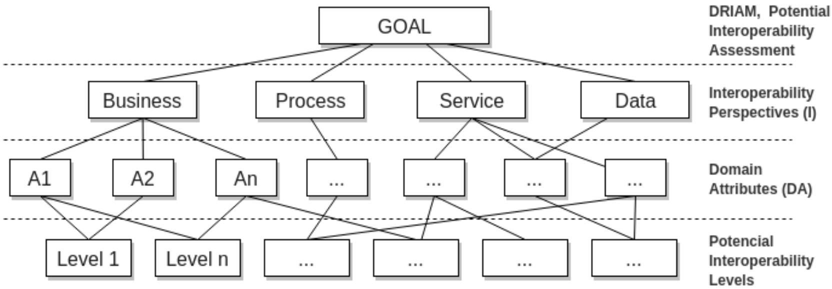

Figure 3. DRIAM AHP Method.

3. Conclusion

It has been shown that crisis management should be linked directly to interoperability issues, allowing an integrated operation of all involved entities during an event. In order to identify the potential interoperation in a disaster response management environment, it is proposed an interoperability assessment framework specific for domain. The proposed method is based on a reference architecture specification (domain attributes vs system requirements), an interoperability diagnosis (domain attributes vs interoperability concerns) of a locality or private or public entity, supporting an interoperable architecture (domains requirements vs interoperability aspects). The proposed framework promotes a review, evaluation and improvement the reference architecture according to the reality of the analyzed entity with respect to its interoperability capabilities. In addition to analyzing the use of other methods to support relational modeling and multicriteria analysis, such as Dematel, the research will continue towards to the improvement of the framework, verifying and validating the found results with ICT public institution of Curitiba and other public entities (civil defense, firefighters, traffic engineering) involved in disaster response management initiatives.

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A Proposal for a BPR Based Method Applied to Higher Education Institutions

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Abstract. The objective of this article is to propose a conceptual model of a method of modelling processes adapted to Higher Education Institutions - HEI, based on the BPR - Business Process Reengineering. HEI is a type of company that has activity focused to provide services, but their operations have specific characteristics and a high level of complexity. The method can be applied in different processes in an HEI, because it covers specifics of the activity for possible significant improvements. To develop the method, the concepts such Operations Strategy added to concepts of Business Process Management, based on the reengineering of processes were applied. The key advantage is that the application of proposed method, can ensure that the process is aligned with the strategy. For the application of the method, a set of six stages are defined. Among the main objectives of process modelling as improvement of processes, at an HEI, you can set its strategy for a certain period; have a certain number of students enrolled in a particular discipline, in a certain language. Therefore, the core activity of the HEI is teaching, since the student must attend a number of disciplines, the institution will offer these disciplines, meeting their demand. However, to move it forward on its strategy, the HEI must not only offer this discipline, but also offer it in a definite language of the strategy plan. The text show an example of educational process modelled according proposed method and discusses the applicability for the different levels processes.

Keywords. Modelling process, operations strategy services, reengineering of processes.

Introduction

The modelling process can be described as a tool used to portray the current situation and simulate the future vision of business processes [1], [2] and [3]. For business processes mean that they are activities in the real world, which consist of a set of logically related tasks and, when executed in a proper sequence and in accordance with the business rules, produce a specific result as described in [4]. Among the main objectives of process modelling can be listed: i) improvement of processes, translated into eliminating unnecessary processes, obsolete and inefficient rules and redundant management; ii) standardization of new processes through consistent documentation; iii) reducing complexity in documentation so that questions can be effectively mitigated by referring to the process documentation; iv) promote dexterity and ease of

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reading; v) be an instrument for creating the homogeneity of knowledge for all team members and vi) full detailed documentation of processes.

In this context as well as other service providers a Higher Education Institution - HEI - is vulnerable to market requirements, changes in the economic environment, seasonality and the inviolability of services [5]. However, due to their type of business, it is subject of specific questions in this niche, as to seek for courses by students, academic performance indicators, selection processes for admission, government financial incentive programs, scholarships, student loans, billing, philanthropy, community service and a number of variables such as: students, teachers, content of courses, academic infrastructure, research, internship activities, focus on preparation for the labour market, internationalization, the students interchange (out/incoming), the information technology systems for academic administration and also their various levels of education, graduate and master graduate [6], [7]. The methods currently available in the literature on modelling process does not include the specific characteristics of a HEI. Thus, as in [7] the complexity levels and the specific situation in a service process in a HEI show the latent need for a separate modelling method, one and only which is built according to the peculiarities of the institution analysed, highlighting the relevance and originality of the method proposed in this paper.

Organizations from various active in the production of goods (manufacturing) or services (operations) extensively use the modelling of business processes in various branches of activity. According to [8], traditionally, operations management was seen as something strictly operating, changing from the '60s, when emerged needs regarding the definition of strategic objectives for the activities of operations because of lack of resources and the need to produce in large quantities to minimize costs, with gains of scale. The goals then became the guarantee that the production processes and delivering value to the customer are effectively aligned with the strategic intentions of the organization and the markets that it intends to win. One of the significant impact observed is that the modelling of business processes has improved the interactions between business interfaces, providing important information on the implementation of its operations.

These improvements allow to better understand the characteristics of the processes making clear the responsibilities of those involved in the operations that compose it [9], [10]. In addition to the interaction of interfaces, the possibility of implementation and reengineering processes combined with optimization of costs and processes critical times, it is one of the main contributions of this work.

1. Background

1.1. Services operations and its peculiarities

Services can have several specific characteristics that distinguish them from manufactured goods. These characteristics should be taken into account, because they better clarify the definition of what is a "service", bringing implications for management.

The comparison between the services and manufacturing is particularly important for the operations management area, owing to the tradition in the management of manufacturing operations.

The differences between the goods and services are widely known in the literature, giving rise to the distinctive features of the services presented by the most renowned authors in the field, as [5] and [11], [12]. Summarizing the characteristics found in the literature, which may overlap and can complement others, so it can be considered that the services have the following characteristics:

- **Intangibility.** Services are intangible by nature, that is, they cannot be touched or owned by the client as manufactured goods.
- **Perishability.** The service takes place at the same time consumption occurs.
- **Inseparability.** One can say that in the services the client is who initiates the production process, and the client participation is what triggers the process.
- **Variability.** The idea of service varies from customer to customer, usually services are activities for people as clients.

As proposed by [11], besides knowing the characteristics of the services, it is important to understand how these characteristics have implications both for research and for services management. Thus, Table 1 lists the characteristics of the services with some of its implications for the management of operations.

Table 1. Characteristics of services and its implications according to [11].

Characteristics	Implications to the operation management
Intangibility	The services are related to perceptions and experiences.
	The evaluation of the service quality by the customer tends to be subjective.
	The physical evidence of the service has a key role (facilities, appearance of staff, etc.).
Perishability	Services cannot be stored.
	The service delivery time is crucial.
	Synchronization between capacity and demand is a critical issue in services.
	In services there is a large overlap between product and process.
	The assurance and quality control should work in process and service delivery.
	In services there is a large interface between the operating functions and marketing.
Inseparability	The client can assume different roles in the service delivery process, including as co-producer of the service.
	The process and the result of the service are influenced by customer participation, so client's management is essential.
	Productivity in services depends on customer participation.
Variability	Each client views the service with a particular view.
	It can be customized to meet the particular expectations of each client.
	The same service provided is provided, but each has a sense of satisfaction.
	The customer places its particular desires when receiving the service

The differences between manufacturing and services contrasts in production systems. The system service operations can be divided into two parts: one that has contact with the client and another that does not [11], [13]. The part that has contact with the client is commonly referred to in the literature of services as frontline. In this part is where interactions occur client/company that can happen in personal or non-personal contact. At the frontline is where occurs the "service meet", which is the period of time that a client interacts directly with a service. The part that has no contact with the customer is called rear-guard. These activities serve to support the service delivery process, and there is little or no contact between the organization and the customer (such as, in the kitchen of a restaurant).

The scope of production is another peculiarity of services. Because of the simultaneity of production and consumption, managers and frontline employees can perform operations and marketing activities at the same time. As there is a large interface between these two functions, often the "operations" is not recognized in services. However, as stated [14] every organization has a function "operations", even if in a particular company it is not called that way. Recognition of activities related to the operations function is fundamental to improve service processes. However, it is necessary to consider the interface between organizational functions, enabling an integrated strategy for service operations.

In this context a discussion of existing specific operations strategies for education is needed, strategies that consider the particularities of this type of service, which as discussed above, the service sector has different peculiarities of consumer goods production sector. To better understand this issue, then a search in the bases literature that exposes some operations strategies applied in education was done.

1.2. Operation Strategies in Education

According to [15], for the strategies in universities, it should be noted that the market often undergoes changes and, therefore, requires new decisions. However, it is possible to trends this market: internationalization, which will lead to a global adjustment in education; scale gains from mergers and acquisitions, reduction of differences between market participants and increasing technology for the sector.

There are HEIs that differentiate themselves by providing innovative undergraduate, others seek to differentiate on price and those who invest in a differentiated educational service. In this context, a university can aim to maximize its results through the modelling of the registration process, because it will result in a significant improvement in the dialogue between the departments involved in the process and also a possible improvement in quality indicators that evaluate this HEI.

Innovations and educational reforms should be designed focusing on the means used by the intuition, by carrying out a detailed examination of the objectives to be achieved, and through a strategic plan to integrate both: means (methods) and end (strategy) [16]. As in source [17] it is necessary to select the means (ways) with the intention of being enough to try to improve the indicators, but before seeking these means, it is necessary to define the purpose, since being strategic is to know where you want to go, understanding the direction, then find the best ways to get there.

For Porter [18], the goal of creating a strategy that is linked to the means available, with the use of human and material resources in a context of market, clearly is: hinder the possible copy of such a strategy by the competitors, making it a competitive advantage.

Some HEIs take as key strategies focus on a certain group of customers, or on a segment of the product line, or in a geographical area, or in an occupational group, or at an organizational level. In Brazil, an HEI who wants to belong to the University level (a type of category of HEI), must meet some minimum requirements by the Ministry of Education (MEC), through the *Guidelines and Bases Law* in [19]. As an example of this, there is the article number 52, the HEI can be characterized as a university if it has, among other issues, at least one third of the faculty with master or doctor titles and a third of the teaching staff in full-time [19].

An opportunity and also a challenge in the scenario of HEI is the fact that its business model is naturally complex, involving expensive physical resources (classrooms, specific laboratories), availability of professors (if the teacher can teach particular subject to certain class at a certain time), availability of groups (if the group no longer has a discipline in a particular place and time), financial resources: minimum number of students in a room, minimum number of students to start a course. Behold, citing some of the many features it is possible to see that the level of complexity of the business model can be a resource optimization opportunity and can maximize results.

Given the complexity of the business model, it is important to reflect on the criteria used in defining strategies, and to create a solid connection between strategy and operation, it is necessary in a university, as well as in any organization, such defined strategies are clear to all involved in the activities, and this need can be met through modelling of processes that provide manuals and documents that guide organizational behaviour. Ensuring that strategy and operation are inextricably connected [20].

1.3. The Business Process Management - BPM

BPM - Business Process Management, is a disciplined approach that meets standards and best practices to identify, design, execute, document, measure, monitor, control and improve business processes, automated or not, to achieve the results in a consistent and aligned way with the strategic goals of an organization [21].

Also [22] defines BPM as "... an assembly of methodologies and technologies designed to enable business processes to integrate, logically and chronologically, customers, suppliers, partners, influencers, employees, and any element which they are able to, want or have to interact with, giving the organization full view and essentially integrated internal and external environment of operations of each participant in all business processes..."

The concepts of process management, involve improvements, innovations and management of business processes that creates value and enables an organization to achieve its strategic objectives with greater efficiency and flexibility [23]. Thus, BPM enables the alignment of processes with the strategic objectives of the organizations, generating with this, improvement and increased performance, through monitoring and implementing improvement of activities. The [21] states that there are some fundamental concepts that define BPM, such as:

- it is a continuous set of processes with a focus on business process management in organizations;
- it includes modelling, analysis, design and measurement of an organization's business processes;
- it is supported by technology through tools for modelling, simulation, automation, integration, control and monitoring of business processes and information systems that support these processes.

1.4. Modelling of Processes

Modelling a process means designing and handling the process, being it mapped or not, that is, in the modelling it is required the registration of the process using particular type of notation [24]. Thus, it is important to note the difference with process mapping. To map a process is the simple statement of the status of the case, of how to draw a picture of the process. When it come to a sketch, the mapping does not need to be performed using a notation.

The modelling process is a mechanism to portray the current situation and describe the future vision of the business processes [25]. The main objectives of modelling process are to ensure:

- processes improvement, aiming to eliminate obsolete and inefficient processes and unnecessary rules and management;

- standardization and ease of documentation, enabling, reading dexterity;
- homogeneity of knowledge for all team members;

The modelling can be performed by localized or global process [2]. The modelling process located, that is, restricted to a particular location or function of the company, makes that there is a common understanding among all project participants on activities, results and who executes the different steps. The project scope can be set quickly and it is possible to find out more specific problems of the analysed process. This form of modelling can be fast in practice because there is no need to document many cases and they are only documented when necessary. For small companies or companies in which business processes change frequently it is the best way of modelling.

Another way is the modelling of globalized processes, that is, map all or key processes. According to [2], the advantages of this type are:

- increasing involvement of employees at work, creating motivation to improve the project;
- expanding the vision of the organization, from the top management, which can identify new improvement projects; and
- identifying, with a greater precision, the processes that can be improved by the individually thereof analysis and in conjunction with other processes.

In order to have an efficient process modelling, Andersen in [2] states that the guidelines of the organization must be discovered and only then identify people, owners, customers and employees who are affected by business processes and to keep expectations for products and services delivered by the company through the business processes that produce these products, services and support.

1.5. Reengineering of processes

To [26], the definition of BPR - Business Process Reengineering - is “the fundamental rethinking and radical restructuring of business processes to achieve dramatic improvements in critical and contemporary indicators of performance such as cost, quality, service and speed”.

The reengineering is emphatic in the aspect of "radically rethink the processes". According to his philosophy, the improvement should be passed over for reinvention from a new initial condition that discards what already exists. As a fundamental principle of reengineering is the discontinuation of the current thinking, that is, recognition and breaking of fundamental rules and paradigms that guided the work as in [26].

According to research carried out, the results achieved by companies that adopt the reengineering have characteristics in common. These characteristics are similar as they are new ways of working processes that were common among all companies. All these companies regarded as efficient the division of labour in simple activities so an employee without any kind of qualification could perform them. The advantages obtained with this organization of work were seen as higher than the disadvantages of having to sequence a variety of processes so, small divided activities could achieve its goal of creating value [26]. When rethinking this way of organizing work, the reengineering has meant that companies could change the way you work.

2. The Proposal of Method

The proposed method unlike the generic modelling methods in the literature, is characterized by the comprehensiveness of the many variables present in a higher education institution, the proposition of a new modelled process without rework waste, without miscommunication between involved elements, with due formalization of activities, ensuring the process and the strategy will walk side by side. Through theoretical framework and the intersection of literature: Operations Strategy, Process Management and Business Process Reengineering with literature support as in Table 2.

Table 2. Description of steps that comprise the method.

Step	Description	Action	Literature Support
1st	Process to be modelled	Definition of Goals and Objectives	Hayes and Pisano [27]; Kaplan and Norton [28]
2nd	Connection with Organizational Strategy	Evidence as it relates to Corporate Strategy	Hayes [17]; Skinner [20]
3rd	Time measuring and flow designing	Collect data that is relevant to the target of the modelling process	O'Connell and Pyke and Whitehead [29] ABPM [21]
4th	Model the current status	One drawing the current state to the future state	OMG [30]; Baldam [31]; Silver [32]; Dale [33]
5th	Implement the generated model	Implement the modelled process proposed	Hammer and Champy [26]
6th	Control / Audit	Check if there is improvement in expected results	Kaplan [25]; Davenport [34]

For its development, the proposed method comprises some steps that was withdrew from literature and, after systematically organization process, it´s been used to facilitate its application in which activities carried out and aimed to provide elements that will be needed during its execution. The established sequence to perform the steps of the method shown here was designed in a way that allows the elements of the processes for a HEI could be easily identified, as to set the processes to be modelled for the activity "scholarship". It makes possible to understand what is the connection between other variables in the second step, pointing it out how the variable students will contribute to the organization's strategy, example given: the HEI defines its strategy to have a specific number of incoming students and out of that number 40% of grant students, the next step will quantify this process, their time and pauses, as the interfaces connected and how this connection's arrangement is done. Another example given: when a student applies for a scholarship, he does it at the designated area for this action, this department collects the request, forwards it to another area that runs a financial analysis, along with another area that is responsible for credit checking procedures verifying economic background of the applicant. After this, the process is depicted to show how process happens, or how it is deployed and mapped. Based on this mapping results a new application process is proposed to change the "modelling" and this change can include an algorithm that automates the analysis involved in, streamlining activity, and makes it less susceptible to human mistakes. It is therefore validated as a possibility of the modelled process, highlighting their contributions. Finally, it is necessary to control the changes, checking if failures are occurring, due to problems of culture or resistance from those involved. The established sequence and literature that supports the proposed method is displayed their following steps, as shown in Figure 1.

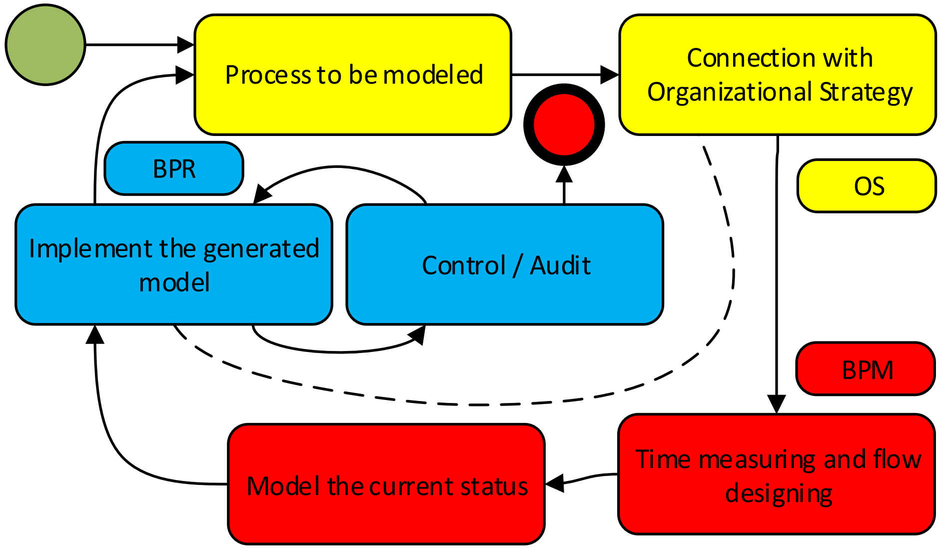

Figure 1. Steps of proposal method.

3. Conclusion: The Application's Possibilities

The article proposes a method based on the characteristics that makes possible to model any process of an HEI, including its peculiarities and variables involved for the student billing, scholarships or exchange students. However, as the main academic contribution, their application enables models after the processes, that had come to contribute to organizational strategy, consolidating its connection.

One possible major bottleneck is the process for international interchange student's reception. The method proposed to realize this process should be standardized, but different from regular students, who are enrolled at the institution and do not requires special treatments, an exchange student will not be familiar to the school environment, and each one in this situation requires a different attendance.

Another important point to be observed is for use/implementation of management systems that are already exhibited and all processes bottom up would be available along the workflow process. So, the HEI can evaluate how your process will have to adapt to its new informational system, or highlight the necessity to build the system oriented to fit the requirements of the process.

Anyhow, the processes operations must be intrinsically in harmony with the organization strategy. However, to move it forward on the way of its strategy, the HEI must not only offer this discipline, but also offer it in certain language in the strategy. Consequently, the main advantage is that the method will ensure that the process is aligned with the strategy defined by HEI, as the result of a process will add the result to the strategy. The method includes the most diverse variables present in a HEI, and proposes a new modelled process that eliminates rework, miscommunication, lack of formalization of activities, it can ensure that the process and the strategy are side by side.

The constrain of the article is that the method has not been applied as a case study yet. The contribution of the paper is to facilitate the integration between real processes with organizational strategic alignment following the method of process modelling for HEIs, and the proposal of process modelling method for higher education institutions based on BPR. Future research may apply this method in order to better verify the results, advantages and possible adjustments that may arise.

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Active Vibration Control Applying H-Infinity Norm in a Composite Laminated Beam

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Abstract. The use of active vibration control techniques applying piezoelectric actuators can show satisfactory results. This paper proposes an active vibration control technique based on H-infinity Norm, which is applied to a piezoelectric actuator bonded to a composite structure forming a so-called smart composite structure. The structural model is stablished for a rectangular shape beam by Serendipity type finite element based on first-order shear deformation theory with eight nodes, five degrees of freedom (DOF) per node and eight electrical DOF per piezoelectric. Furthermore, a mixed theory that uses a single equivalent layer for the discretization of the mechanical displacement field and a layerwise representation of the electrical field is adopted. Temperature effects are neglected. Simulation results show the effectiveness of the proposed control methodology for composite structures.

Keywords. Active Vibration Control, H-Infinity, Composite Materials.

Introduction

In the last few years, there is a great interest in researches about composite materials that possess innovative layouts, characterized by low weight, mechanical resistance and the possibility of optimization to specific work conditions. Such materials are made of fiber layers that can be oriented in specified directions, which enables them for singulars applications.

The addition of piezoelectric layers to composite materials offers a wide application area, such as precision positioning and active vibration control. The association of composite materials with piezoelectric layers is known as Smart Composite Structure. The representation of the behavior for the Smart Composite Structures is achieved through Mixed Theory, based in one equivalent layer to discretize the mechanical displacement field and another to represent the electric field [1]. In the current work, both electrical and mechanical fields are represented by Finite Element Model, by means of Hamilton’s Variational Principle, which takes into account all the energy that is present in the structure.

The number of publications related to the development of new active vibration control techniques increases in recent years. Many of them show successful results.

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The present work models a Smart Composite structure, which is a fixed beam in one end, and uses modal active vibration control to optimize the performance of this dynamical system. The aim is to improve the dynamical response behavior, considering uncertainties in the model. For the control it was used the minimization by H-infinity Norm.

1. Modeling of a Smart Composite Structure

1.1. Mechanical Deflection Field according to the Mixed Theory

The mechanical behavior of a structure, according to the Mixed Theory is represented by the First Shear Displacement Theory (FSDT), given by Equation 1:

$$\begin{aligned} u(x,y,z,t) &= u_0(x,y,t) + (z\psi_x(x,y,t)) \\ u(x,y,z,t) &= v_0(x,y,t) + (z\psi_y(x,y,t)) \\ w(x,y,z,t) &= w_0(x,y,t) \end{aligned} \tag{1}$$

where u_0, v_0 and w_0 are the displacements in directions x, y and z, respectively. The plane x-y is the material plane and ψ_x ψ_y are the rotation regarding x and y, respectively.

The mechanical variables in Equation 1 are achieved by shape functions and nodal variables using Finite Element Method. The element considered in this formulation is known as Serendipity, which is a planar element with three nodes per side, resulting in eight nodes per element [2].

From the FSDT, the mechanical displacement as function of nodal coordinates is obtained:

$$\{U(\xi,\eta,z,t)\} = [A_u(z)][N_u(\xi,\eta)]\{u_e(t)\} \tag{2}$$

where $\{U(\xi,\eta,z,t)\} = \{u(\xi,\eta,z,t)\}\ \{v(\xi,\eta,z,t)\}\ \{w(\xi,\eta,z,t)\}^T$, $[A_u(z)]$ is the matrix of the thickness variables in z direction as functions of the five displacements $(u_0, v_0, w_0, \psi_x\ e\ \psi_y)$, $\{u_e(t)\}$ is the vector that contain all the nodal variables and $[N_u(\xi,\eta)]$ is the dynamical matrix of the mechanical function for the beam.

The elongation is expressed as function of shape functions and nodal variables, shown in Equation 3:

$$\{\varepsilon(\xi,\eta,z,t)\} = [B_u(\xi,\eta,z)]\{u_e(t)\} \tag{3}$$

where $[B_u(\xi,\eta,z)] = [D(z)][N_u(\xi,\eta)]$, $[D(z)]$ is the matrix that contains differential operators present in the strain-displacement relation, which is detailed in [3].

1.2. Linear Electrical Potential Distributed in the Structure Layers

After reaching the mechanical displacements, it is necessary to deal with the electrical field calculation. Through the Mixed Theory, the electrical potential is expressed by Equation 4, in which the direction along the thickness z is uncoupled from the reference plane x-y.

$$\varphi(x,y,z,t) = \sum_{j=1}^{nc+1} L_j(z)\varphi_j(x,y,t) \tag{4}$$

Where $L_j(z)$ is related to the function of equivalent layers, and $\varphi_j(x,y,t)$ is the interface function of the j-th interface of the composite constituted by *nc* layers.

The electrical potential described in the local coordinates for the k-th layer and e-th layer element is expressed by Equation 5, also originated from finite element formulation.

$$\varphi(\xi,\eta,z,t)_e^k = [N_\varphi(\xi,\eta,z)]\{\varphi_e(t)\} \tag{5}$$

Where the matrix of the electric shape functions $N_\varphi(\xi,\eta,z)$ is associated to the serendipity shape functions and Lagrangian interpolation functions $\{\varphi_e(t)\}$ that contain the nodal values for the electrical potential.

Applying the definition of electric field as negative gradient of the electrical potential, the expansion of the electric field for the k-th layer is expressed by Equation 6:

$$\left\{E(\xi,\eta,z,t)_e^k\right\} = -\nabla[\mathrm{N}_\varphi(\xi,\eta,z)]\{\varphi_e(t)\} \tag{6}$$

where $\vec{\nabla}[N_\varphi(\xi,\eta,Z)] = [B_\varphi(\xi,\eta,z)_k]$ [3].

1.3. Elementary Matrix

When modeling a smart structure, the coupling between the composite structure and the piezoelectric element is achieved by means of Hamilton's Variational Principle, which incorporates all energy distribution present in the structure. According to [4], the elementary coupling matrices are shown from Equation 7 to Equation 10:

$$\left[M^e\right] = \int_{Ve} \rho[N_u]^T[A_u]^T[N_u]dV_e \tag{7}$$

$$\left[K_{uu}^e\right] = \sum_{k=1}^{nc}\int_{\xi=-1}^{+1}\int_{\eta}^{+1}\int_{z=z_k}^{z_k+1}\left([B_u]^T[c][B_u]\right)Jdzd\eta d\xi \tag{8}$$

$$\left[K_{u\varphi}^{e}\right]=\sum_{k=1}^{nc}\int_{\xi=-1}^{+1}\int_{\eta}^{+1}\int_{z=z_k}^{z_k+1}\left(\left[B_u\right]^T\left[e\right]^T\left[B_\varphi\right]\right)Jdzd\eta d\xi \quad (9)$$

$$\left[K_{\varphi\varphi}^{e}\right]=\sum_{k=1}^{nc}\int_{\xi=-1}^{+1}\int_{\eta}^{+1}\int_{z=z_k}^{z_k+1}-\left(\left[B_\varphi\right]^T\left[\chi\right]^T\left[B_\varphi\right]\right)Jdzd\eta d\xi \quad (10)$$

where ρ is the material density, $\left[M^e\right]$ is the mass elementary matrix, $\left[K_{uu}^e\right]$ is the stiffness elementary matrix and both $\left[K_{u\varphi}^e\right]$ and $\left[K_{\varphi u}^e\right]$ are elementary matrices of the electric-mechanical coupling. $\left[K_{\varphi\varphi}^e\right]$ is the dielectric elementary matrix. $[c]$, $[e]$ and $[\chi]$ are respectively the matrices of, elastic stiffness, piezoelectric stress and permittivity matrices, all formed by constant values. $\left[B_u\right]$ and $\left[B_\varphi\right]$ are input matrices and V_e is the elementary volume. J ís the Jacobian of transformation [2].

Based in the previous equations, the global model matrix, presented in Equation 11 is built through a standard procedure in which g indicates global magnitude.

$$\begin{bmatrix}\left[M_g\right] & 0\\ 0 & 0\end{bmatrix}\begin{Bmatrix}\ddot{u}_g\\ \ddot{\phi}_g\end{Bmatrix}+\begin{bmatrix}\left[K_{uu}\right] & \left[K_{u\phi}\right]\\ \left[K_{\phi u}\right] & \left[K_{\phi\phi}\right]\end{bmatrix}\begin{Bmatrix}u_g\\ \phi_g\end{Bmatrix}=\begin{Bmatrix}\left\{F_g\right\}\\ \left\{Q_g\right\}\end{Bmatrix} \quad (11)$$

Where $\left\{F_g\right\}$ and $\left\{Q_g\right\}$ are respectively, the generalized force and the electric charge.

2. Control Approach

The modal active control is an advantageous technique, which is very effective when applied in flexible structures, because these structures require a reduced number of sensors and actuators.

In the present work, modal active control is employed to control the smart composite structure. In Figure 1, there is a scheme of the arrangement for the modal control, where δ corresponds to the displacement, X to the modal state, F_{exc} to the external force and u represents the control effort.

The estimator acts to determine the modal states demanded by the controller, however, in order to apply the Kalman Estimator, it is necessary that the model be represented in the state space form. Therefore, in the control scheme in Figure 1, the smart composite structure, expressed by Equation 11, is denoted in the space state form as in Equations 12 and 13, in order to enable them for numerical simulations.

The Kalman Estimator is used when it is desired to reduce the effects of noises in both input and output signals, to estimate the states and the outputs of the system [6]. Equation 12 represent the Kalman Estimator:

$$\{\dot{x}_r(t)\} = [A_r]\{x_r(t)\} + [B_r]\{u(t)\} + [L]\{\delta(t) - \bar{\delta}(t)\} \tag{12}$$

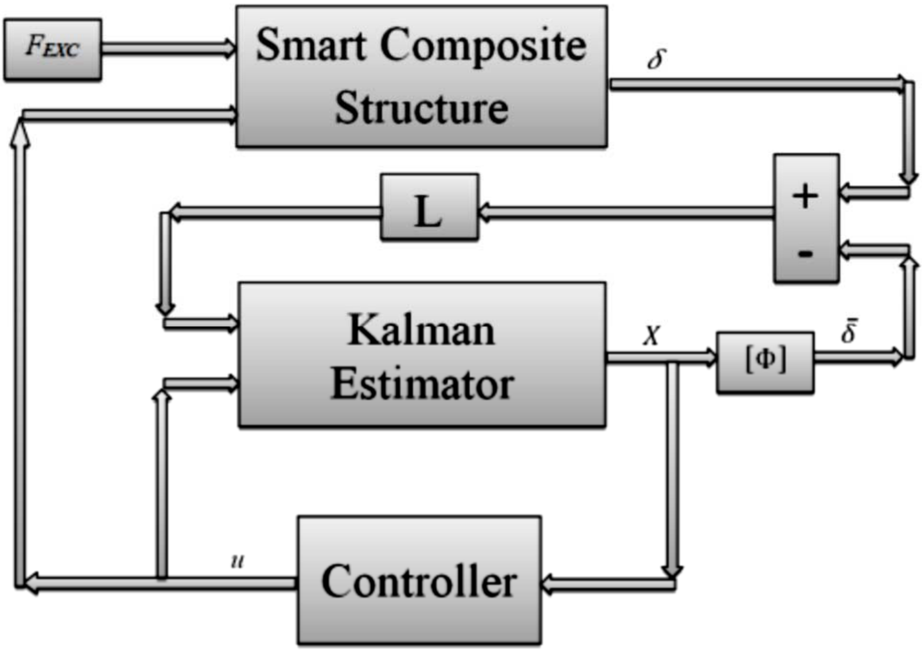

Figure 1. Active modal control based on modal state feedback control (adapted from [5]).

where $[A_r] = \begin{bmatrix} 0 & I \\ -M^{-1}K & 0 \end{bmatrix}$ and $[B_r]=[0 \;\; M^{-1}]^T$, $[L]$ is the observer gain matrix, determined by lqe.m in Matlab® *software*, $\delta(t)$ is the displacement vector and $\bar{\delta}(t)$ is the estimated displacement vector.

The output equation is as follow:

$$\{\delta(t)\} = [C_r]\{x_r(t)\} \tag{13}$$

In Figure 1, it can be observed that in the modal state, the feedback require modal displacements and velocities to determine the control effort. In the current work, it was used the H-infinity Norm as controller.

3. Norm H-infinity

In [7] it is shown how to calculate de norm H-infinity by LMIs. The H-infinity Norm can be solved by using the following optimization convex problem:

$$\|G\|_{\infty} = \min \mu$$
$$\begin{bmatrix} A^T P + PA + C^T CPB \\ B^T P - \mu \end{bmatrix} < 0 \tag{14}$$
$$P > 0,\ \mu > 0$$

where μ is a scalar. Therefore the controller gain is achieved when μ is minimized.

4. Numerical Simulation

The smart laminated beam structure analyzed in this work is illustrated in Figure 2. The beam has a 306*mm* length, 25.5*mm* width and 1*mm* thickness, and it is composed by five layers of graphite/epoxy 0.2*mm* thickness each layer. The layers are oriented as [45º /0º /45º /0º /45º], where 0º refers to a direction parallel to *x* axis.

The piezoelectric ceramic actuator is attached to the upper side of the beam, 1*mm* far from the fixed end, with 1*mm* thickness and dimensions of 45.9 x 25.5*mm*.

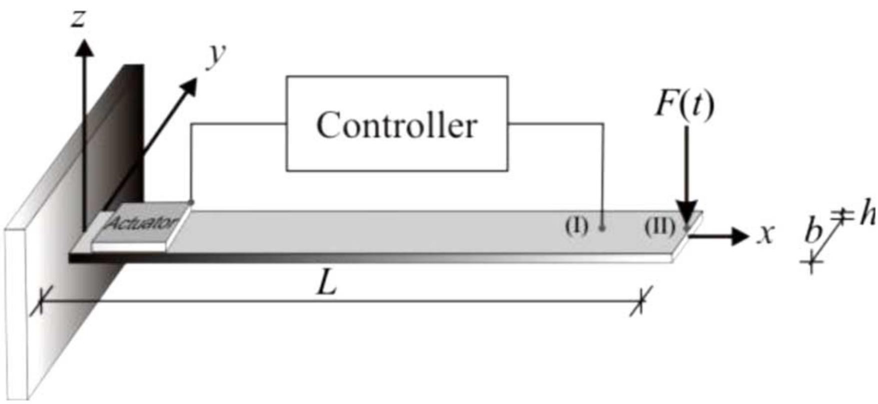

Figure 2. Laminated beam one fixed end with active vibration control (From [8]).

The constants of elastic stiffness of the beam, made of graphite/epoxy (AS4/3501) given in [*GPa*], are respectively:

$c_{11} = 173.6$; $c_{22} = c_{33} = 7.61$; $c_{12} = c_{13} = 2.48$; $c_{23} = 2.31$; $c_{44} = 1.38$; $c_{55} = c_{66} = 3.45$.

The piezoelectric stress constants:

$c_{11} = c_{22} = c_{33} = 102.23$; $c_{12} = c_{13} = c_{23} = 5.035$; $c_{11} = c_{22} = c_{33} = 102.23$; $c_{44} = c_{55} = c_{66} = 2.594$.

The piezoelectric electric constants in [*C/m²*] are: $e_{31} = 18.300$, $e_{32} = e_{33} = -9.013$.

The electric permittivity, given in [*F/m*], are: $\chi_{11} = \chi_{22} = \chi_{33} = 1800\varepsilon_0$. The density of the composite structure and of the piezoelectric material, given in [kg/m^3], are respectively 1578 e 7700.

The excitation force of *1 N* was applied at point (II), as shown in Figure 2 and the responses in the time domain were measured at point (I). The piezoelectric actuator is connected to an active control system, and the amplitude of vibration is minimized. In order to have more similarity possible with an experimental condition, white noise were added in the displacement calculation.

Robustness analyzes were performed considering uncertainties of (±10%) in the dynamical matrix of the state space and also in the Kalman Estimator model. The balanced realization was used to reduce the model to the first two vibration modes of the structure, given that the system is both controllable and observable when considering these modes.

Regarding control, three cases were analyzed, the first was the deterministic, the second considered non-parametric uncertainties in the model of the smart composite structure, the uncertainties were inserted directly in the dynamical matrix of the system model, and in the third case, the uncertainties were input in the Kalman Estimator model.

5. Results

The first important results is that for the first two modes considered, the system was indeed observable and controllable. Then, the methodology discussed was applied to the system. For this condition the response of the system was analyzed in both time and frequency domain, presenting the voltage used in each case

The first case was the deterministic case in order to verify the efficiency of the proposed methodology. Figures 3, 4 e 5 show the control results.

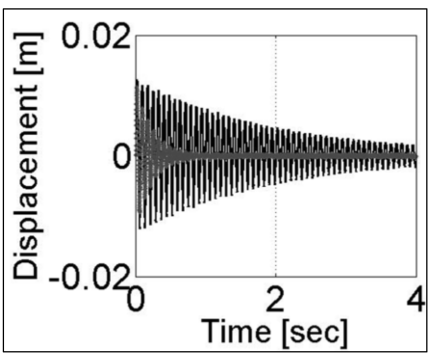

Figure 3. Impact Response control off (black line) and control on (gray line).

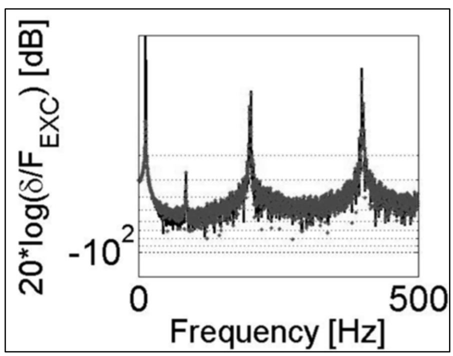

Figure 4. Frequency Response Function: control off (black line) and control on (gray line).

In Figure 3, it can be observed that the system was controlled, and the response was completely attenuated after *1.0 s*. Figure 4 shows that the control strategy was capable of expressively reduce the first mode of the system. Figure 5 shows the voltage due to the control effort of the piezoelectric actuator.

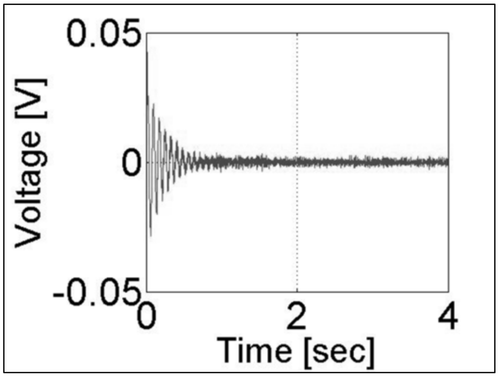

Figure 5. Control effort.

Figures 6, 7 and 8 show the results for the second case.

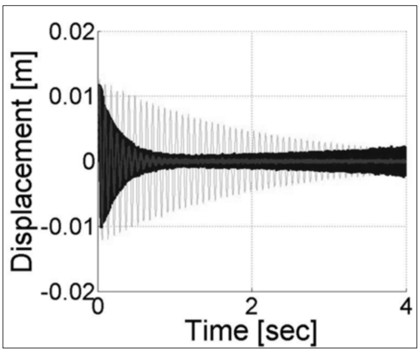

Figure 6. Impact Response: control on (gray line), envelope (black) and control off (light gray line).

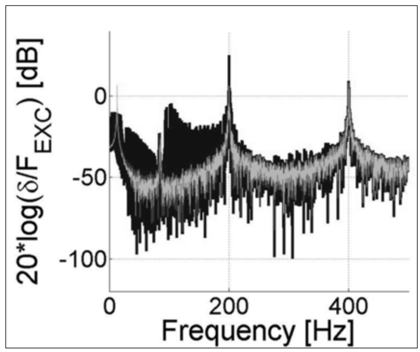

Figure 7. Frequency Response Function: deterministic (light gray line) and envelope (black).

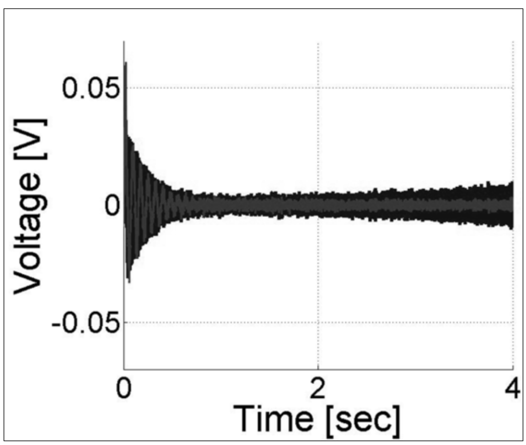

Figure 8. Control effort: deterministic value (gray line) and envelope (black).

In terms of impact response, it is noticeable that the system response was attenuated, as can be seen in Figure 6, where the light gray line represents the system without control. It can be observed robustness of the controller until a certain period shown by the small envelope (in black), however in a posterior moment it can be noticed that this envelope increases, what characterize instability of the system in steady state. The same tendency was observed in terms of control effort in Figure 8. The FRF in Figure 7 shows that the two modes considered for controlling were reduced, however there is an increase of the third mode, demonstrating the Spillover effect, which causes increase in the steady state envelope.

In the third case, it was considered uncertainties in the Kalman Estimator model. Figures 9, 10 and11 show the results for this case.

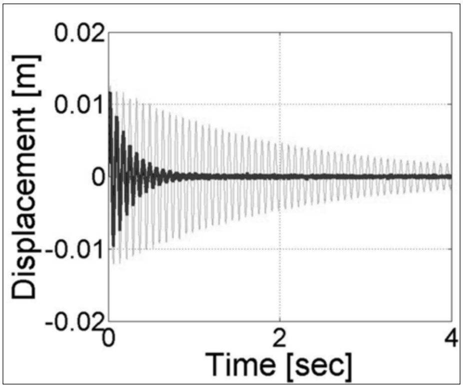

Figure 9. Impact Response: contron on (gray line), envelope (black) and control off (light gray line).

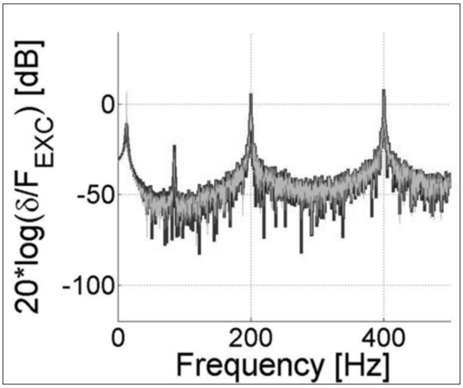

Figura 10. Frequency Response Function: deterministic (light gray) and envelope (black).

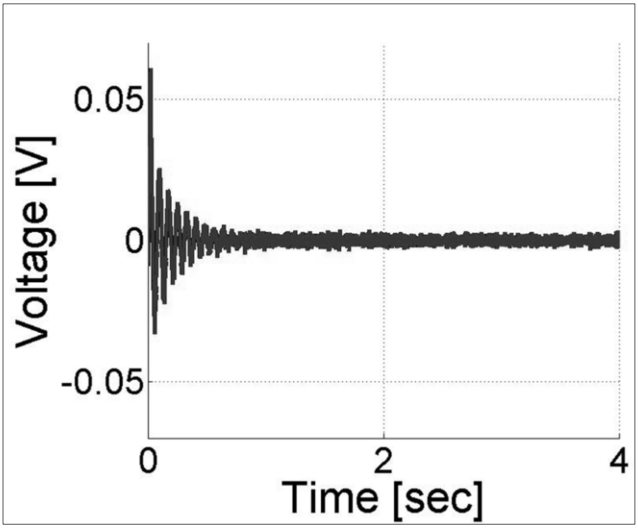

Figure 11. Impact Response: control on (gray line) and envelope (black).

From the graphs presented in Figure 9, 10 and 11 it is noticeable that the condition considering uncertainties in the Estimator model, considerably approaches the real model for all measured values, showing more robustness in this case than in the previous cases.

6. Conclusion

The current work deal with the study of active vibration control in smart composite structures through the control by H-infinity Norm. The numerical results had shown that the control was effective to attenuate the beam vibration using a piezoelectric actuator. They also reveal that the number of modes considered, which in this case were two, had been sufficient to achieve satisfactory control results. It is worth comment the importance of the balanced realization at this stage, given that this technique classifies the modes in order of relevance, allowing the consideration of the most important modes to the system response. The analysis had shown the robustness of the system, mainly in the third condition analyzed, which occurred even with the uncertainties added to the estimator model. The results obtained matched the values of the deterministic methodology.

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Design of Software Development Architecture Comparison of Waterfall and Agile Using Reliability Growth Model

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Abstract. This paper proposes a method for deciding whether to insert an agile process as part of a waterfall project. Recently, many software projects adopt an agile software methodology. Still, some software is developed with traditional waterfall methodologies. Agile methods claim a strength of flexibility for uncertain changes, yet in some cases the initial expected scope of the project cannot be realized or undetected errors remain because schedules are fixed and unexpected backlog of tests and bug fixes remain unaddressed. On the other hand, a waterfall methodology can include high risk of violating schedule targets, while fulfilling the initially expected scope with comprehensive tests so that more complex products are reliable. For the decision whether to develop in waterfall or agile, our approach is to evaluate the effects on uncertainties by adoption of agile techniques. We begin with focus on uncertain rework. The effects on rework are evaluated as cost using simulation. The decision making problem is modeled as a decision tree. In the simulation, a Software Reliability Growth Model is used as an error likelihood and detection model. This proposed method is demonstrated using a simple shopping web site. As a case study, the effects on rework by adoption of agile can be evaluated using the developed simulator. With comparison of predicted rework costs given a balance of waterfall or agile methods for a specific case, the project can be designed more effectively.

Keywords. Decision Making, software development methodologies, Agile, simulation, project design

Introduction

For software development, especially massive software systems, traditionally a waterfall methodology is used. Software systems are composed of some subsystems, referred to here as “modules”. In a waterfall approach, modules are first designed, then developed, tested, and reviewed together in each stage [1]. Given this characteristic of strong sequence, the waterfall methodology makes the project difficult to respond to unpredictable changes due to technical problems or changes demanded by customers. Small changes might require large rework across the previous stages of the project.

In this decade, some software companies have transformed from a waterfall methodology to an agile software development methodology [2]. An agile methodology emphasizes local teamwork with adaptability to uncertain changes [3].

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With agile, the project's unit of progress is called a sprint or iteration. Each iteration has five task types within that period: *plan*, *design*, *develop*, *test* and *review*. Each module is developed in an iteration, and a project can adapt to sudden changes at the review task without waiting for equivalent progress across all modules. Figure 1 shows task flows of a waterfall project and an agile project. In Figure 1, the modules are listed according to the effect they have on the other modules. In doing so, this rule of order can reduce the tasks to rework when a sudden change happens.

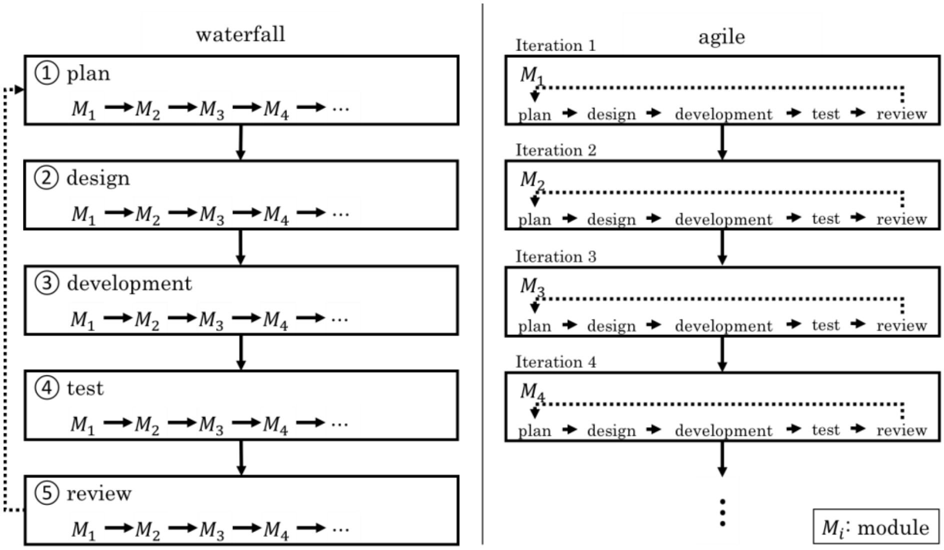

Figure 1. Example of task flows in waterfall/agile methodology.

Although there are many agile projects, it is not a warranty of success to adopt agile for software development [2]. The complexity of scope or the likelihood of requirements change in a project may drive situations in which waterfall outperforms agile. This paper proposes a method for decision making whether to adopt an agile development methodology rather than a waterfall project. The objective is to evaluate the effect on adoption of an agile methodology to a software development considering the requirements changes and system complexities. In this study, it is assumed that reworks are caused by a sudden change in requirements of the modules at the review task and undetected error in the test task. A concept of decision tree [4] is used for modeling of this decision making problem. Uncertainties are dealt with Monte Carlo simulation. The dependencies between modules are expressed by Design Structure Matrix (DSM) [5]. An error detection model is based on the S-shaped Software Reliability Growth Model (SRGM) [6].

The remainder of this paper is composed as follows. Section 1 reviews the waterfall and agile literature in relation to this study. Section 2 describes the proposed method. Section 3 uses a simple example of Electronic Commerce (EC) system developing project as a case study. Section 4 discusses the case and analyzes the sensitivity of the developed simulator. The last section concludes this paper.

1. Related works

After the Agile Manifesto [3] was published, there have been many industrial experience reports about adoption of the agile methodology [7]. Sureshchandra et al. [8] conducted training on agile and gradually transformed from a waterfall project to agile. He showed that although transforming the waterfall project takes some effort, it is possible. Svensson et al. [9] conducted experiments to introduce an agile process to software maintenance and evaluated organizations. Their research evaluated how easy it is to introduce agile using a method based on the Analytical Hierarchy Process (AHP), which is a tool to compare objects subjectively. In the case of insertion of agile into a traditional waterfall project, it is also necessary to consider how agile might impact quality. Huo et al. [10] qualitatively compared the agile development model with waterfall model in terms of quality assurance.

Of course, in the real world, a project has many uncertainties. The consideration of uncertainty in development projects has an extensive research literature. We focus here on uncertainties which drive rework in software development projects. Eppinger [11] and later Browning [5] use the Design Structure Matrix to anticipate how project architecture and dependencies can cause project delay, more iteration, increased cost, reduced quality, or failure to meet requirements. By recognizing tasks uncertainty in a project model, the chance (or risk) of project variation due to uncertainty can be estimated. Luh et al [12] showed how the inclusion of these uncertainties in a project model can be used to optimize project scheduling. In both these cases however the trade-off with scope quality were not analyzed.

In order to consider these uncertainties, Monte Carlo simulation is often used. Moser introduced an agent-based simulation with unclear tasks scope and selection of attention given realistic global project dependencies [13]. Mitsuyuki et al. [14] developed a simulator to evaluate a waterfall process. There are some studies about agile using simulation. Uribe et al. [15] optimized the tool selection for agile manufacturing capacity planning using simulation. Turnu et al. [16] simulated the defects for Test-Driven Development (TDD) and non-TDD in agile project.

Most of these studies discussed above refer to projects that are predominantly waterfall or agile. For those studies comparing agile with waterfall, consideration of the systemic consequence of key uncertainties is missing. Given the key advantage claimed by agile users – the adaptability to sudden change – and that most programs require a mix of agile and waterfall [17, 18, 19, 20], we propose to consider these phenomena together. Therefore, as a first step this paper presents a simulator for the waterfall and agile processes and the simulation includes the rework caused by requirements change.

2. Methodology

This section gives the method proposed in this paper. The problem addressed by this paper is the choice of the better method, waterfall or agile, for a software development project considering uncertain rework.

In this paper, the problem is modeled as a decision making problem, whose elements are designated and described as Table 1. This proposed method is constructed based on these elements. The model for each simulated scenario begins at first with a decision whether or not the scenario will use a waterfall or agile approach. As such, the architecture of the software development project changes. Next, each module has a chance that the customer will request a change, causing planned rework. Next, the scenario is expanded based on whether or not an uncertain error occurs and is detected at the testing task, triggering rework. Such error for a given module can occur more than once in a scenario. In turn, errors detected in a module can propagate the need for rework to other modules.

Table 1. Elements for notation of decision making problem.

Name of element	Element description
Decision maker	Project manager
List of stakeholders	Development company, customer and users
Target of time span for the problem	2 months (60 days)
Objective function	Cost of rework caused by requirements change and undetected errors
Constraint condition	The organization model and base of system requirements such as needed modules are given and fixed.
Parameters to effect on objective function	
Uncertain parameters	Amount of reworks, the points of requirements change and error detection
Certain parameters	The point of the decision making to select the waterfall or agile is only before the development start.
Excluded parameters	Additional modules and developers, operation of the software and development in parallel

This scenario is modeled using decision tree. A decision tree is one of the tools for decision making and it has a recursive structure for expressing classification rules [5]. A decision tree has decision nodes, uncertain nodes and expected utilities. The decision making problem is represented with a decision tree, as shown in Figure 2. In Figure 2, decision nodes have branches of waterfall and agile. There are two type of branches going out from an uncertain node. One of them is how many undetected errors remain, and/or the other is if that module changes or not. The leaves of the decision tree are defined according to the expected cost of the rework incurred by the undetected errors and/or the changes in the modules. It is too complex to calculate the probabilities and the expected values for all scenarios because the uncertain nodes are too many and they contain continuous values. The simulation is used in order to overcome these complexities.

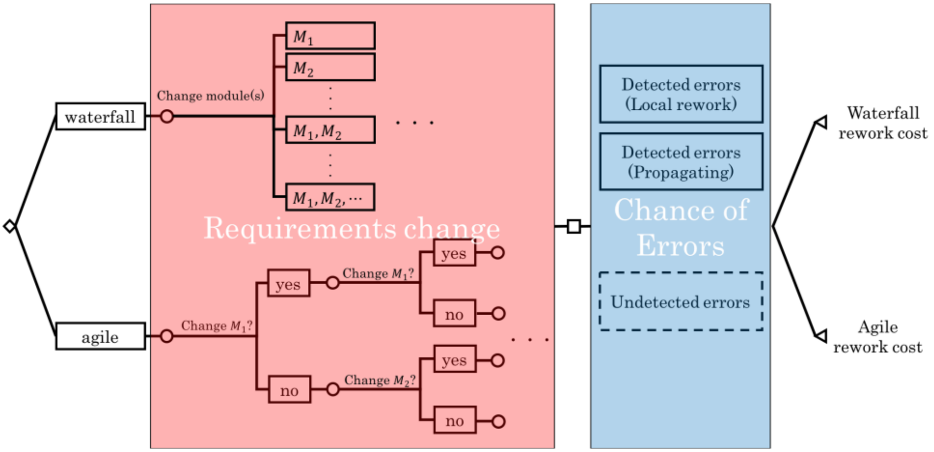

Figure 2. Scenario including project architecture decision, customer change of requirements, module error, propagating change due to related tasks.

The proposed method's parameters are defined in Table 2, and Figure 3 shows an overview of the approach. The objective of this approach is to compare the rework cost in the waterfall and agile processes, evaluated by simulator taking into account the development model and the organization model. The input data of the simulator is consisted of four models. First input data is the information on the modules of the software under development. The information on the modules, expressed by M_i , includes the durations needed for each tasks and rework rate. Next input data is dependencies between modules and task flow. These are described in the section 2.1. The last input data is the organization model. The data on the organization has the task type that each team contribute, cost per person-day and the mean values of the error occurrence rate and error detection rate. The output data comprises the mean values and standard deviations of the rework costs calculated by the simulator, individually and an as an aggregate of the elements.

Table 2. Parameters description.

Name	Details	Parameter
Module information	This contains required duration (person-day) and requirement change rate.	M_i
Organization model	This contains the number of developers, cost (USD per person), λ and b.	T_j
Total cost of rework	This is the sum of the cost of rework incurred by requirement change and undetected error.	c_{rework}
Requirements change rate	This is the rate of changing requirements [0, 1]	r_{req}
Total Error	Total error increases in developing tasks and decreases in testing tasks.	$N(t)$
Mean of error generation rate	The mean of error generation rate per person-day	λ
Mean of error detection rate	The mean of error detection rate per person-day	b

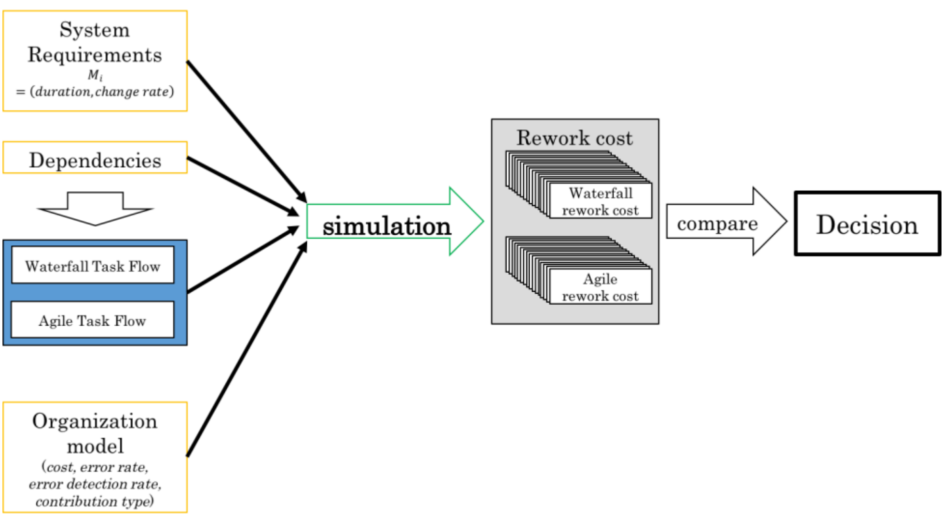

Figure 3. Overview of the proposed method.

2.1. Dependencies between modules and task flow model

In the simulation, the dependencies are used to distinguish tasks in need for rework from finished tasks. When a change in plan of a module happens, the need for rework propagates to the other modules which depend on the module changed. The plan changes happen based on the change rate of the module set in the simulation. To represent this dependencies between modules, Dependency Structure Matrix (DSM) is generally used. DSM also helps managing the sequence of the developing process [5]. In this proposed method, DSM is used for representing i/o dependencies between modules. Once dependencies modules are determined, the tasks' execution control flows, for both waterfall and agile, are generated according to Figure 1.

2.2. Developing process simulation

In the developed simulator, the rework cost is calculated by a following simulation process:

1. Initialize the data and set time $t = 0$.
2. Pop the first task from the list of tasks not yet started and set the state of task *DOING*.
3. Put the task forward Δt.
4. Update the state of the task.
5. If the doing task finish, add the task to first of the list of finished tasks. If not, back to 3.
6. If the list of tasks not yet started is empty, it is the end of simulation. If not, back to 2.

Δt is the time step forwarded and basically one day. However, if the remained amount of work to be done is less than a day, Δt become the amount remained to be done.

If the type of the task is *review*, requirements change happen according to r_{req} of the module reviewed. Once the rework happens, the doing task and the tasks that the models depend on the module changing in the list of finished tasks are initialized and added to the list of tasks not yet started. After the list of tasks not yet started is updated, the list is reordered in a sequence of the waterfall or the agile described in Figure 1. The simulation restart from the step 2.

If the type of the task is *develop*, errors are generated as the task steps forward. In this paper, the error generation is regarded as a Poisson process with mean value of error generation rate per person-day λ. Then the number of total errors of the whole systems $N(t)$ are updated by the Equation (1) where m is the number of the developers and k_l is a Poisson random value.

$$N(t + \Delta t) \leftarrow N(t) + \Delta t \sum_{l=1}^{m} k_l \tag{1}$$

If the type of the task is *test*, errors are detected by test as the task moves forward. The errors are detected according to the Software Reliability Growth Model (SRGM) [6]. SRGM is the model generally used for evaluation of software reliability. The error detection process in the SRGM is based on the nonhomogeneous Poisson process

(NHPP). The general NHPP software reliability growth model is formulated based on the following assumptions [21]:

1. The detection of software errors follows an NHPP.
2. The software error intensity rate at any time is proportional to the number of remaining errors in the software at that time.
3. When a software error is detected, a debugging effort task place immediately. This debugging is independent at each location of the software errors.

Under these assumptions, mean of the number of detected errors $n(t)$ in a time step Δt is simulated by the Equation 2 where b is the mean value of the error detection rate and $N(t)$ is the number of total software errors.

$$n(t) = N(t)(1 + bt)\exp(-bt) \tag{2}$$

The number of detected errors per person-day d_l follows a Poisson distribution $\Pr\{d_l = k\}$ defined by Equation 3.

$$\Pr\{d_l = k\} = \frac{[n(t)]^k}{k!} e^{-n(t)}, \quad k = 0,1,2,\cdots \tag{3}$$

Then the total error $N(t)$ is updated in testing task by Equation 4.

$$N(t + \Delta t) \leftarrow N(t) - \Delta t \sum_{l=1}^{m} d_l \tag{4}$$

The rework cost is calculated with the cost of rework occurred by the requirements change c_{req} and the cost of rework supposed to need to fix the undetected errors c_{error} as Equation 5. The c_{req} is calculated simply by Equation 6 where $t_{\text{add, req}}$ is the duration for rework occurred by requirements change. Regarding c_{error}, it can be calculated by Equation 7 using SRGM because the duration required to fix the all errors $t_{\text{add,error}}$ can be simulated by Equation 2 and 3. Therefore, the rework cost can be obtained as a result of simulation.

$$c_{rework} = c_{req} + c_{error} \tag{5}$$

$$c_{req} = m \cdot c \cdot t_{add,req} \tag{6}$$

$$c_{error} = m \cdot c \cdot t_{add,error} \tag{7}$$

3. Case study

In this case study, the proposed method is demonstrated using a simple shopping web site developing project. This web site has five modules, basic, search, purchase, payment and delivery. These modules has a system requirements described in Table 3.

Table 4 shows the dependencies between these modules by DSM. The organization model is used as Table 5.

Table 3. System requirements for each modules.

M_i	Module name	Required duration (person-days) (plan, design, develop, test, review)	Requirement change rate
M_1	Basic	(1, 5, 12, 4, 1)	0.05
M_2	Search	(1, 5, 12, 4, 1)	0.05
M_3	Purchase	(1, 5, 12, 4, 1)	0.05
M_4	Payment	(1, 5, 12, 4, 1)	0.05
M_5	Delivery	(1, 5, 12, 4, 1)	0.05

Table 4. DSM representing the i/o dependencies between modules.

Input\Output	M_1	M_2	M_3	M_4	M_5
M_1	-	0	0	0	0
M_2	1	-	1	0	0
M_3	1	0	-	0	0
M_4	1	0	1	-	0
M_5	1	0	1	0	-

Table 5. Organization model.

Number of developers	Cost (USD per person-day)	Error generation rate (per person-day)	Error detection rate (per person-day)
3	10,000	1.0	1.0

The result shows in Table 6. In this case, they will decide agile because both of the expected rework cost and standard deviation is lower than the waterfall.

Next, sensitivity analysis is conducted changing the requirement change rate from 0 to 10%. Figure 4 shows the result of this sensitivity analysis.

Table 6. Result of the case that requirements change rate is 0.05.

Methodology	Expected rework cost (10^3USD)	Standard deviation (10^3USD)
Waterfall	8.31	25.09
Agile	2.82	3.42

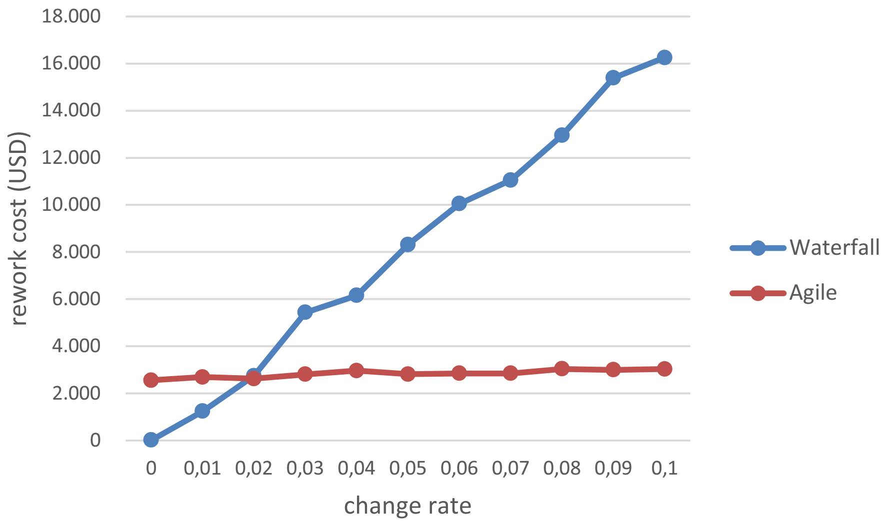

Figure 4. The result of the sensitivity analysis.

4. Discussions

According to Table 6, it can be seen that the expected rework cost above a certain change rate of the waterfall methodology is higher than the cost of agile. We might consider that a project which requires (or permits) many changes will have an ongoing rework cost that is more sustainable than the risk of these changes in a waterfall project. Moreover, the standard deviation of the waterfall is much higher than one of the agile. This shows the waterfall development can be higher risk than the agile development if the system requirements could be changed.

In the Figure 4, two lines cross at the point of that the requirements change rate is about 0.02. In the case of that the requirements change rate is 0, which means no requirements change, the rework cost of the waterfall is roughly 0 and that of the agile is higher. This shows the testing tasks are enough to detect most of the errors for the waterfall methodology. This result shows testing tasks should be increased in agile methodology because it is more difficult to detect errors in the agile than the waterfall. In this simulation model, this difficulty in the agile is caused by $N(t)$ in the Equation 2. In the agile, the number of errors $N(t)$ is less than that in the waterfall. Generally, this additional tests in agile are conducted as the integration tests. This integration tests should be considered for more practical simulations.

5. Conclusion

The effect to adapt the agile methodology can be evaluated considered uncertainties of reworks by this proposed method. The uncertainties of rework can be calculated by using simulation. The case presented in this paper is limited. In the future we will model a case from a real software development project. Also, this framework has limitation in not considering the variation of change rates across phases nor variation of error detection capabilities across an organization. Also, in the real world, the combination of waterfall and agile is needed [17]. The framework will be extended to examine multiple project types, varying complexity, size, exception handling, and other factors that lead to changes in real world projects. Our intent is to leverage this framework for design of a project that has some portions that are agile, and other portions waterfall.

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Part 9

Optimization of Engineering Operations and Data Analytics

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Aerodynamic Features Optimization of Front Wheels Surroundings for Energy Efficient Car

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Abstract. Constant development of the vehicles energy efficiency, the fuel prices and the requirements for greenhouse gas emissions force designers to find new solutions to achieve the goals by minimising the movement resistances. As it was calculated basing on the research carried out at the Silesian University of Technology, the Institute of Fundamentals of Machinery Design on energy efficient cars designed for the Shell Eco-marathon race, the main component of the total resistance of a moving car is the aerodynamic drag which is equal, in such a type of car, to about 70% of the total movement resistance. The idea of the research is to optimize the shape of aerodynamic features of the front wheels surroundings. By the front wheel surroundings aerodynamic features, the front wheel arch and front bumper shapes are understood. The air drag depends on the elements of the drag coefficient c_x which is strongly connected with its shape and its area. Front wheel in motion rotates and generates air turbulences which have negative influence on the car aerodynamics. In majority of the cars the front wheels are swivel, which makes it difficult or impossible to close the front wheel arch. For reduction of the air drag generated by the open wheel arch, three types of solutions are designed and optimized. The first solution is the main shape of the analysed car parts which are shaped so that they generate minimal aerodynamic drag and lead the air stream to bypass the wheel niche. The second analysed solution is passive system consisting of respectively shaped holes in the front bumper. The holes lead the air stream into the wheel niche, equalize pressure in the wheel niche and reduce the air turbulences generated by the rotating wheel. The last solution is a set of overlays which lead the air stream in such a way to avoid its disruption to the wheel arch niche and achieve the best air stream distribution around the vehicle.

Keywords. Finite element method, Energy efficient car, Aerodynamics, CFD

Introduction

Constant development of the vehicles energy efficiency, the fuel prices and the requirements for greenhouse gas emissions force designers to find new solutions to achieve the goals by minimising the movement resistances [1,2]. As it was calculated basing on the research carried out at the Silesian University of Technology, the

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Institute of Fundamentals of Machinery Design on energy efficient cars designed for the Shell Eco-marathon race, the main component of the total resistance of a moving car is the aerodynamic drag which is equal, in such a type of car, to about 70% of the total movement resistance [3,4,5]. The idea of the optimization is to optimize the shape of the front wheel surroundings aerodynamic features. By the front wheel surroundings aerodynamic features, the front wheel arch and front bumper shapes are understood. The air drag depends on the elements of the drag coefficient c_x which is strongly connected with its shape and its area. Front wheel in motion rotates and generates air turbulences which have negative influence on the car aerodynamics. In most of the cars the front wheels are swivel which makes it difficult or impossible to close the front wheel arch.

Numerical computational aerodynamic studies represent a significant part in the design and optimization of car bodies. In comparison with tunnel based research, carrying out research using numerical methods [6,7] is relatively faster and less expensive. Based on numerical methods of calculation it is possible to simulate any ambient conditions, referred to as boundary conditions and visualize the distribution of parameter values as desired, for example the pressure distribution on the surface of the vehicle or the air speed distribution in the plane coinciding with the plane of symmetry of the car. Depending on the developed model, numerical methods [6,7] could provide high accuracy data. Their results can be compared with ongoing tunnel research on the physical model. This type of research—using virtual models created in a CAD environment eliminates necessity to manufacture physical model of the object of every developed version of optimized object, which significantly increases the costs of development process. Such approach makes it possible to determine the right direction of its development and to optimize its shape for the lowest aerodynamic drag in the early stages of the car body surface design process. Optimisation of vehicle aerodynamics considering its influence on total vehicles movement resistance is extremely important. It allows a significant reduction in the size of the required power units, which is associated with reduction of vehicle total weight and the energy absorbed by the power unit. Due to the continually rising fuel prices as well as environmental considerations in the current trend of the development of the automotive industry, vehicle weight reduction and energy consumption are very important issues.

1. Theoretical description of the studied phenomena

In fluid mechanics, there are different flow distributions due to different criteria. From the aerodynamics point of view, the division of flow due to the motion of fluid particles is important [2,3]. Consistent with this criterion the flow may be laminar or turbulent. Laminar flow [7] is a stratified flow, where the fluid flow creates a parallel, smooth layer. Depending on the shape of the walls of the object on which the fluid passes, the flow lines are straight or gently curved. The flow of this type is for small and medium speed for contractual Reynolds numbers less than *2300*. Turbulent flow [7] is characterized by the presence of time-varying flow disturbances, so-called turbulences, manifesting with blenders fluid particles. The characteristics of the flow are variable in time and space. Turbulent flow occurs at high flow velocities Reynolds numbers above *2300*.

Aerodynamic forces acting on the car in motion in air [8,9]. have several components. The components of the aerodynamic force relevant to the issues to be analysed are components acting along the longitudinal axis of the vehicle (so-called drag force) P_x (1) and the lift P_z (2).

$$F_x = \frac{1}{2} * \rho * S * v^2 * c_x \quad (1)$$

$$F_z = \frac{1}{2} * \rho * S * v^2 * c_z \quad (2)$$

where:

ρ is the air density, S the surface area of the object, v the speed, c_x coefficient of drag forces.

Other forces and moments acting on the car in motion are the lateral force *Fy*, the pitching moment *My,* heeling moment *Mx,* deflection moment *Mz*.

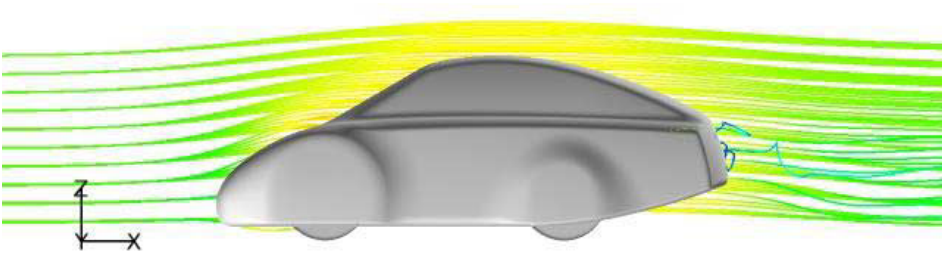

Figure 1. Flow directions in CFD aerodynamics.

Aerodynamic resistance [8÷11] is a movement counter force. Natural coordinate system of the tested issue is the coordinate system of a vehicle. However, it is preferable to adopt analysis system associated with the axes of the vehicle, since the vehicle is stationary and air is moving. A very important factor for consideration for car aerodynamic drag is a dimensionless drag coefficient c_x [8÷11]. It is associated with the shape of the body. The greater the drag coefficient, the greater the aerodynamic drag of the vehicle. Coefficient c_x is determined by measuring analytically drag forces. Boundary layer [8÷11] is a layer of medium flowing in a short distance from the surface of the test object. In the boundary layer, there are significant changes in speed. On the surface of the object the speed of of medium flowing over the test object is equal to zero, and increases to the set speed with the distance from the surface. The phenomenon of the boundary layer is related to the fluid viscosity. It is very difficult to determine unambiguously the thickness of the boundary layer. It is assumed that the value of the boundary is the place where the speed is 1% in comparison with the set speed.

2. Methodology

2.1. Aerodynamics CFD

The aerodynamic simulations were preformed in a virtual wind tunnel with a length of 15.5 m, height of 2.5 m and width of 1.2 m Due to the vehicle symmetry the analyses were conducted for its half to reduce the computing time. The selection of the tunnel size [10,11] parameters has been carried out experimentally. The length and height of the tunnel were selected on the basis of air velocity distribution on the vehicles symmetry plane. The tunnel width was selected so that the side turbulence lines do not exceed the tunnel borders. The object of interests was the vehicle front wheel surrounding. To increase the simulation accuracy, the ground movement and rotation of the front wheels were applied. The vehicles drag surface was covered with 7-layer boundary layer. Simulations were performed for a medium flowing in the form of air, having a temperature of 25°C, pressure of 1013,25 hPa (1 atm) and an initial speed of 10 m/s. As a model for the simulation of turbulence Spalart-Almaras model with turbulence coefficient equal to 5% was used. As a baseline for the analysis of air flow in the wind tunnel default software parameters were adopted. Any deviation from the baseline parameters used in the analysis are the parameters that give adequate accuracy at the same time the demand for computing power. Simulation conditions were chosen according to the conditions during the Shell Eco-marathon race in Rotterdam and in accordance with generally accepted principles of research in the tunnel of the Institute of Aviation in Warsaw [10,12]. In this study, it was achieved by the distribution of the drag forces and pressure distribution on the surface of the vehicle. On the basis of the obtained values of the aerodynamic drag force on the surface of the vehicle aerodynamic coefficient c_x was analytically calculated (1). The obtained results were validated analysing result change due to the mesh size change. The model was regarded as correct when the further decrease of the FEM [13,14] mesh size does not significantly change the obtained results.

2.2. Optimization

Optimization process [15÷18] consists of a couple of sub processes (Figure 2). Based on the simplified CAD model, the vehicle is aerodynamically analysed according to the methodology described in the *Methodology* chapter.

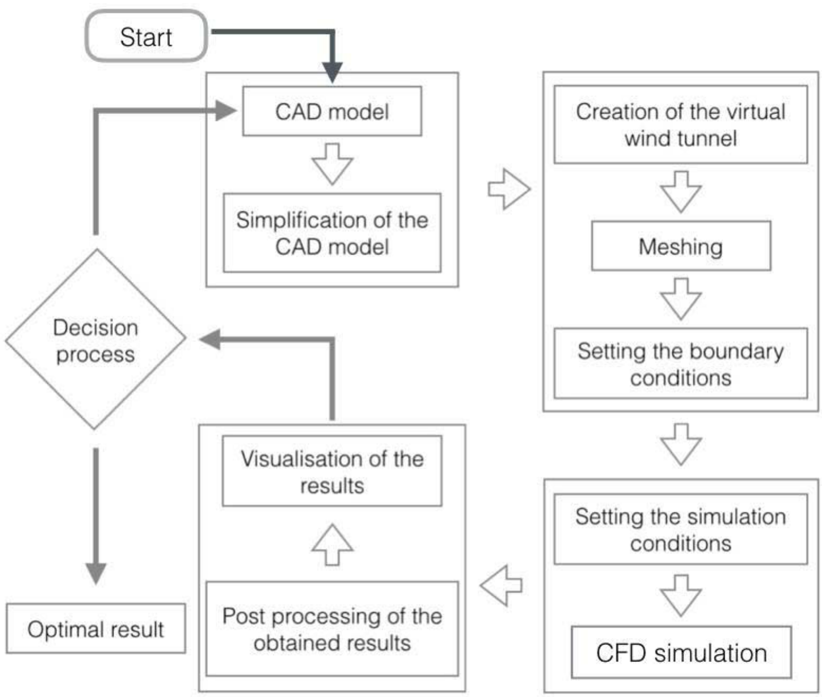

Figure 2. Optimization methodology diagram [19,20].

The optimization was carried out iteratively. After each iteration the set of obtained results was analysed — the drag coefficient, the drag force of the whole vehicle and the flow streamline distribution in the front wheel surrounding. Then it was decided if the solution can be considered as an optimal one and the optimization can be stopped, or should be changed and the optimization should be continued.

Firstly, the problem ratio was indicated. The streamlines for the basic version of the front wheel surrounding are the indicators of the areas that are disturbing the air streamlines in that way that the drag force of vehicle increases. In the second phase of optimization the shape of the wheels surrounding parts were optimized, i.e.—front bumper and front wheel arch. The criteria of reduction are their drag coefficient and achievement of the optimal streamline distribution to avoid its falling into the wheel arch hole (Figure 3). The next step of optimization was to design and optimize a set of holes in the front bumper that will lead the part of the air stream from the place with the highest pressure (the tip of the bumper) to the wheel arch hole to blow out the turbulent air from its inside. The last part of optimization was to design and optimize additional deflectors for the front wheels surrounding that lead the blow out stream from the wheel arch hole. The optimization has been stopped when, the further shape changes were not giving satisfactory improvement and the size limits were achieved.

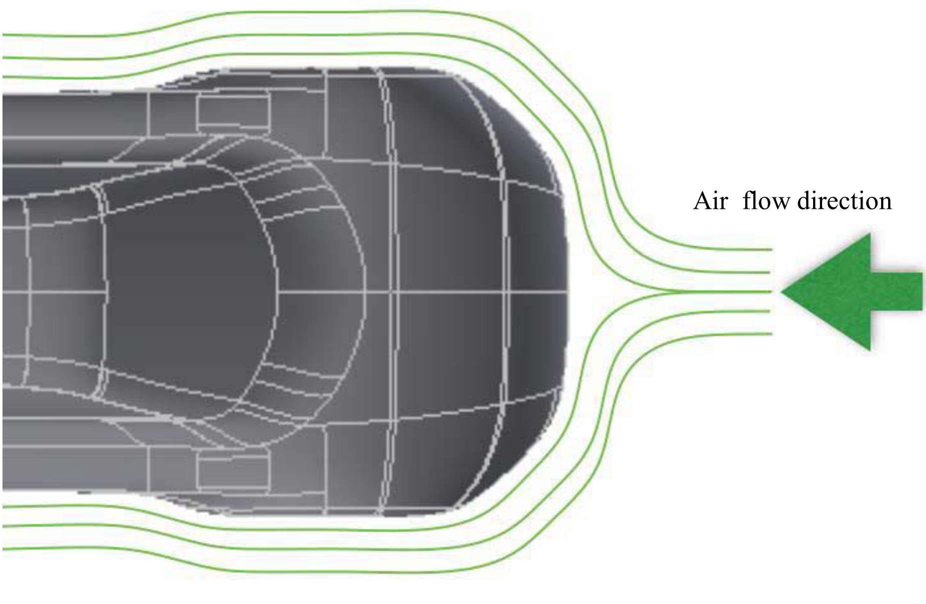

Figure 3. Visualisation of the protection shield idea.

The geometry has been parametrized. In optimization process the set of the geometric parameters has been changing selectively. Parametrization includes the design variables relation and assumption that the cross sections of optimized parts (inlet channels) are constant to avoid air flow turbulences. In the optimization process possible wide parameter area was searched. The design parameter sets are different for each optimized part. For the inlet channels parametrization the authors decided tofollow such design parameters as size and shape of the channels inlet cross section. For the front bumper parametrization the authors decided to follow design the following parameters: radii of curvatures of the bumpers cross section in two perpendicular surfaces with assumption of constant width of the bumper. For the wheel arch deflector parametrization the authors followed such design parameters as width, height, length of the deflector and the curvature radius of the deflector face.

3. Results

The base for identification of the critical regions was the visualisation of the pressure distribution on the vehicle surface. As it can be recognized (Figure 4) the highest pressure appears on the front tip of the vehicle. From this area all of the air streamlines begin to encircle the vehicle. Other region that can be mentioned according to the optimization of the front wheel surroundings is the back wall of the front wheel arch hole. It is a region of high air pressure caused by combination of the wheel rotation and irruption of the air stream encircling the bottom part of the vehicle.

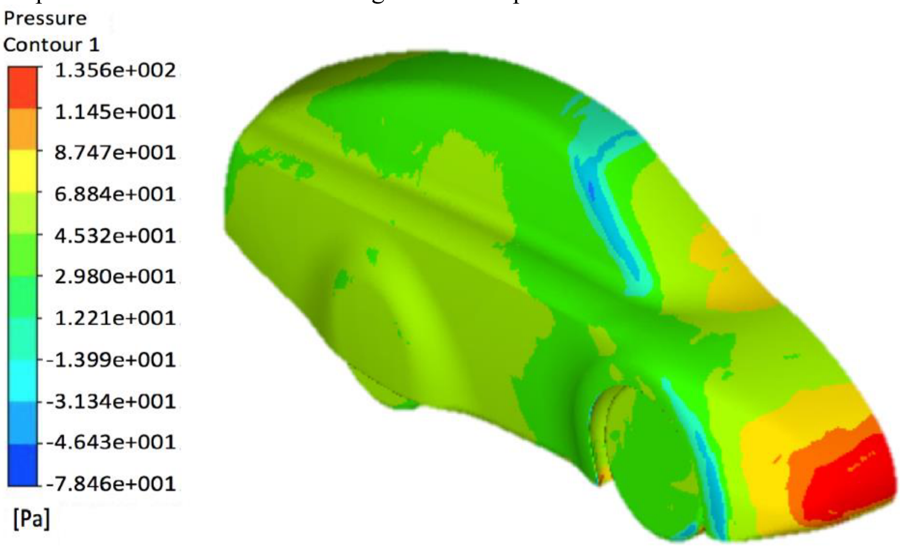

Figure 4. Visualisation of the pressure distribution on the vehicles surface before optimization.

3.1. Optimization of the front bumper shape

After the first optimization stage—optimization of the front bumper shape, the vehicles aerodynamic characteristic has been changed. In the table (Table 1) the optimization results are included. The first compared bumper version (Bumper v1*) is the input, non optimized version of the vehicles part. As it can be observed the total vehicles drag coefficient c_x and its aerodynamic drag force decrease for the next optimized versions. Comparing the results for input bumper version with the best achieved solution, the drag coefficient c_x and drag force were reduced by 15%. The drag area has not changed significantly.

Table 1. Comparison of the results for optimized bumper shape.

	Vehicles drag coefficient c_x	**Vehicles drag force [N]**	**Drag area [m^2]**
Bumper v1*	0,3498	21,66	1,059
Bumper v2	0,3198	19,80	1,060
Bumper v3	0,3195	19,78	1,065
Bumper v4	0,2997	18,57	1,060

3.2. Optimization of the front bumpers inlet channel.

After the second optimization stage—optimization of the front bumper inlet tunnels (Figure 5) the vehicles aerodynamic characteristic has been also changed. According to the figure (Figure 5) the air from the region of highest pressure gets into the inlet tunnel reducing the air pressure on the bumpers tip. The outlet of the tunnel is located inside the wheel arch gap. The tunnel has constant cross section over the entire length to minimize the flow turbulences. The air stream incoming through the tunnel blows off the turbulent air stream generated as the consequence of the wheel rotation. In the table (Table 2) the optimization results are included. The first compared bumper version (w/o tunnels*) is the input part from the first step of optimization without inlet channel. The decrease can be observed of the vehicles coefficient c_x and its aerodynamic drag force. The exception is the *Tunnel v1* which significantly increases the drag area what affects the higher vehicle drag coefficient. For every version of the inlet tunnels the increase of the drag area can be observed which is caused by the appearance of additional drag surfaces inside the front bumper.

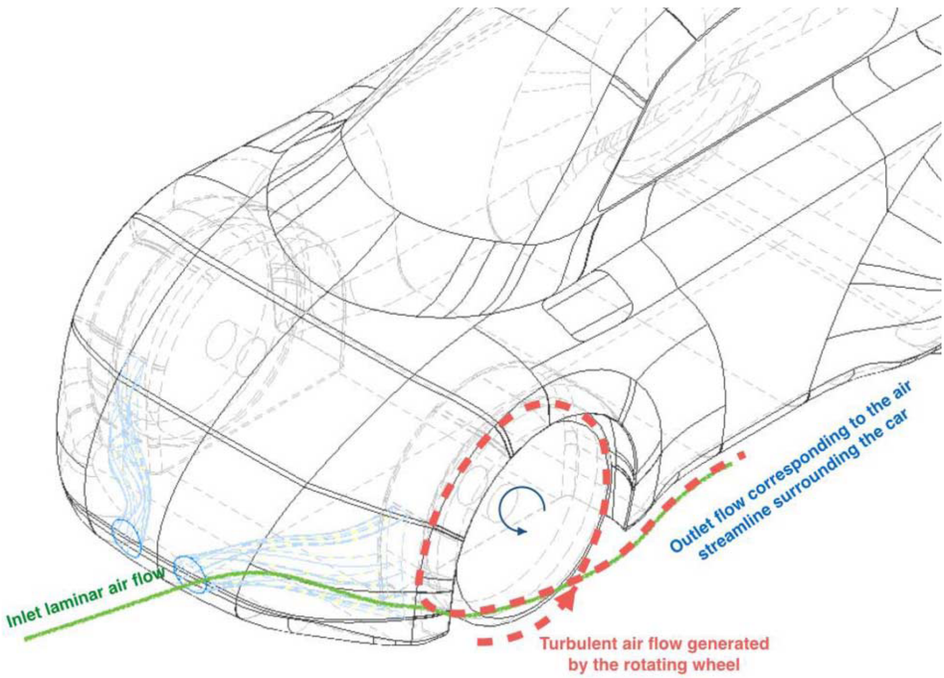

Figure 5. Front bumper air flow tunnels principle of operation.

Comparing the results for input bumper version with the best achieved solution, the drag coefficient c_x and drag force were reduced by 8%.

Table 2. Comparison of the results for optimized bumper inlet tunnels.

	Vehicles drag coefficient c_x	**Vehicles drag force [N]**	**Drag area [m^2]**
w/o tunnels*	0,2997	18,57	1,060
Tunnel v1	0,3101	20,12	1,090
Tunnel v2	0,2850	18,51	1,063
Tunnel v3	0,2769	17,97	1,062

3.3. Optimization of the wheel arch surrounding.

After the last optimization stage—optimization of the wheel arch surrounding (Figure 6) the vehicles aerodynamic characteristic has also been changed. In the table (Table 3) the optimization results are included. The first compared bumper version (w/o deflector*) is the last geometry of the second stage optimization.

The deflector (Figure 6) is mounted inside the wheel arch gap to lead the air stream generated by the wheel rotation in the way that it changes its back edge and minimizes the air pressure inside. The air stream irruption into the wheel arch gap was significantly reduced with the front bumper shape so the deflector helps to reduce the influence of the turbulent flow generated by the rotating wheel.

The slight decrease can be observed of the vehicles drag coefficient c_x and its aerodynamic drag force. The exceptions are the *Deflector v1* which bring no significant changes or and *Deflector v2* which has negative influence on the vehicles aerodynamic drag. For every version of this solution only a little increase of the drag area can be observed which is caused by the low drag area of the deflector. Comparing the results for input bumper version with the best achieved solution, the drag coefficient c_x and drag force were reduced by 2%.

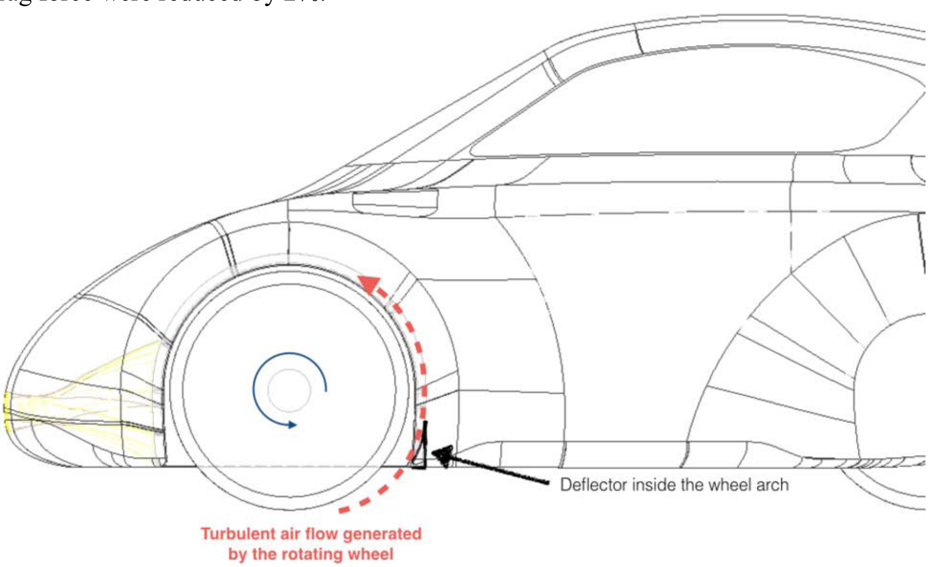

Figure 6. Wheel arch deflector principle of operation.

Table 3. Comparison of the results for optimized wheel arch surrounding.

	Vehicles drag coefficient c_x	Vehicles drag force [N]	Drag area [m^2]
w/o deflector*	0,2769	17,97	1,062
Deflector v1	0,2771	18,04	1,063
Deflector v2	0,2830	18,42	1,062
Deflector v3	0,2714	17,67	1,062

4. Conclusions

The research contains the optimization of the front wheels surrounding of the energy efficient car. By changing the front bumper shape, adding inlet tunnels and deflector the irruption of the air flow streamline into the wheel arch gap was reduced which consequently leads to reduction of the vehicles air drag. In the total optimization process 23% reduction of the vehicles drag coefficient c_x was achieved. The design changes affect also the air pressure distribution on the vehicles surface (Figure 7). The regions of high pressure were significantly reduced and the high air pressure on the tip of the front bumper was used to reduce the air pressure inside the wheel arch gap. As it can be noticed the optimization was carried out for the case when the car moves straight. The impact of the stream at an angle – change of the direction of the car cases were not analysed. Due to the different and non-symmetric wheels arrangement (when the car turns the left wheel position in relation to the wheel arch gap is different than the right wheels) such solution may bring different, even worse results than the non-optimized one. Improving the optimized vehicle with movable deflectors—flap regulation in the bumper inlet tunnels and movable deflector at the ends of the front bumper can adjust such solution for different turn angles.

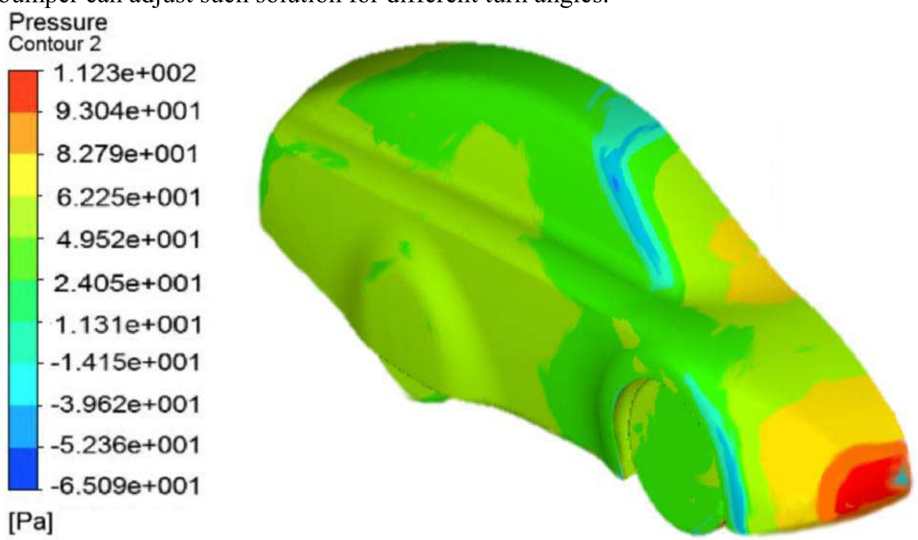

Figure 7. Visualisation of the pressure distribution on the vehicles surface after optimization.

Considering the fact, that for such a vehicle the 70% of the movement resistance is the aerodynamic drag, such solution which reduces the air drag by 23% can meaningfully improve vehicles energy efficiency. It is particularly essential in comparison with ending resources of fossil fuels and pollution and thermal gases emission reduction. Applied changes in analysed vehicle give significant air drag reduction. Optimized issues were observed in CFD simulations. The vehicle was manufactured as a prototype and takes part in Shell Eco-marathon competition. Conducted optimization is an answer for the need to reduce the movement resistances of existing vehicle. Further air drag reduction will require new body design.

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Adapting Nautical Technology for Aircraft Emergency Location Tracking in a Maritime Environment

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Abstract. This paper discusses an investigation into retrofitting a standard nautical Emergency Position Indicating Radio Beacon (EPIRB) on aicraft. The proposed solution will eject the EPIRB automatically away from the aircraft prior to water impact to ensure that it falls clear of any debris. For this system to be accepted by aircraft operators the retrofit needs to be cost effective and reliable with additionaly consideration being required for maintenance and installation. The selected location cannot interfere with the existing aircraft structural integrity and performance so as to avoid costly certification. The EPIRB ejecrion system will need to activate automatically under pre-determined conditions so as to allow succesful deployment of the EPIRB even if the aircraft breaks apart during descent. Once the beacon is in water the EPIRB will begin to transit GPS coordinates so its position is able to be tracked as it drifts on ocean currents.

Keywords. EPRIB, adapting, retrofit, aviation, nautical, eject, automatically,

Introduction

Federal Aviation Regulation 91.207 requires aircraft to carry an Emergency Locator Transmitter (ELT). The ELT is attached to the airframe and is automatically activated after impact on land. In the event of an aircraft impacting water, the capabilities of an ELT are severely diminished as it is not designed to operate in and under water. Recent accidents have shown that aircraft are currently not well equipped to signal their location in case of an accident on water.

The maritime authority requires the carriage of an Emergency Position Indicating Radio Beacon (EPIRB) on surface vessels. EPIRBs are designed to float and transmit GPS coordinates at 406 MHz to the COSPAS/SARSAT satellite system that beams the information back to ground stations to prompt an emergency response. An EPIRB signal can be received in less than 5 minutes, allowing a rapid response with an increased chance of saving lives. An EPRIB built into an aircraft could potentially be a cost-effective means to locate and track aircraft in water.

The two incidents involving Air France Flight 447 and Malaysian Airlines 370 show that current technologies cannot guarantee that an aircraft location can be pinpointed accurately when they disappear over water. Aircraft over water are not under radar surveillance and rely on flight crew reporting their position over VHF radio.

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The aim of this project is to use the existing nautical technology of an EPIRB and adapt it to aviation to address the limitations of an ELT by providing a solution that will address the search and rescue difficulties in major aircraft incidents where the aircraft has crashed into water.

This paper discusses the concept design of the ejection system. Topics of the design process discussed include dynamic simulations determined the necessary ejection force required through flight path optimization. As well as this the sensors and the conditions required to eject the beacon at the optimal time prior to impact are discussed.

1. Emergency Position Indicating Radio Beacon (EPIRB)

The EPIRB considered for this project is the Kannad Marine SPORTPRO+. The specifications for this EPRIB can be seen in Table 1. This particular EPIRB contains small lithium metal batteries and the EPIRB has been approved to be taken on board passenger aircraft as a personal item in carry-on hand baggage. This is because the overall low level of lithium content of the EPIRB and is classified as “non-restricted” as air cargo under IATA packing instruction – PI 970. Additional to this registration of 406MHz satellite EPIRBs with the EPIRB Registration Section of the national authority is mandatory, due to the global alerting nature of the Cospas-Sarsat system.

Table 1. Kannad Marine EPIRB Sport+ specifications [6].

EPIRB Type	Kannad Marine Sport, Sport+	Class 3, Non float free
Operation	Manual activation	Switch, protected by anti-tamper seal.
	Self test button	Checks transmitters, battery and high intensity LED
406 MHz Transmitter	Operating frequency	406.040 MHz ± 1 kHz
	Power output	5 W typical
	Modulation	Phase (16K0GID)
121.5 MHz Homer	Operating frequency	121.5 MHz ±3.5 kHz
	Power output	50 mW radiated typical
	Modulation	Swept tone AM (3K20A3X)
GPS Receiver (Sport+ version only)	Centre frequency	1.57542GHz
High intensity LED	Type	High intensity LEDs
	Light output	0.75 cd minimum
Antenna	Vertical	Whip
Battery	Type	Lithium metal
	Operating life	48 hours minimum
	Storage	7 years
	Replacement	By service centre
	Use	Logged by microcontroller
Environment	Operating temperature	-20 °C to +55 °C
	Storage temperature	-30 °C to +70 °C
	Waterproof	Immersion to 10m
	Buoyancy	Floats
	Exterior Finish	High visibility yellow
Physical	Weight	Without GPS 609g With GPS 615g
	Height of body	21 cm
	Length of antenna	18 cm
	Overall	39 cm
	Lanyard	5.5m, 40Kg breaking strain
Fixing	Two part Bulkhead bracket	Removable Carrysafe collar
Standards applied	Satellite system	Cospas-Sarsat T.001/T.007
	EPIRB	IEC 61097-2, AS/NZS 4280.1

As shown in Table 1, there are a number of parameters which make this EPRIB suitable for the project. The operating life of 48 hours provides a significant amount of time for search and rescue teams to co-ordinate and pinpoint a location. The storage life of the battery is 7 years meaning that costs associated with maintenance required is reduced because of the long battery life. The operating temperature means that the EPIRB will be able to function effectively in any marine environment and in conjunction with this the storage temperature which the EPIRB is able to withstand means that it is able to be stored aft of the rear pressure bulkhead without the need for additional insulation. The size of the Kannad Marine Sport+ adds to its adaptability as its packaging footprint is reduced which then influences the size of the ejection system. A detailed drawing of the EPRIB can be seen in Fig. 1.

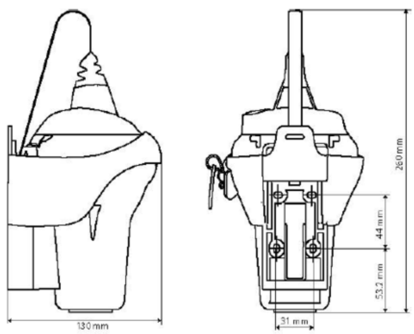

Figure 1. Kannad Marine Sport+ EPIRB dimensions [6].

Fig. 1 shows that the EPRIB is designed to be stored with the antenna folded. In the event of ejection, the antenna would "whip" out and be in its intended position for functionality. The conditions which activate an aircraft ELT are different to those which activate an EPIRB as an EPIRB is not designed to be placed under high g-loading that an aircraft may experience in a crash. However, the major challenge faced is not being able to install an EPIRB in an aircraft or activating the EPIRB as it can function as intended after an aircraft crashes into water but actually being able to eject the EPIRB away from the aircraft prior to it impacting the water. A number of conditions must be met for an EPIRB to be adapted for aviation purposes. These include:

1. Withstanding high loads which will be experienced from ejection and when the EPIRB strikes the water.
2. Must be stored at pressures and temperatures being experienced inside the non-pressurised aircraft section at cruise altitude.
3. Must be ejected automatically clear from the aircraft to avoid being trapped by the wreckage. For example, minimum half of the horizontal stabilizer span.
4. Must be fitted on the aircraft with minimal impact on the original structure and aircraft performance.
5. Must be reliable and economically viable.

The Kannad SPORTPRO+ EPIRB selected for this project is a second generation EPIRB. A study by the Global Area Wireless Technology Research Group ETRI [6] investigates the development and performance of second generation 406 MHz EPIRBs.

An image of the way in which the COSPAS SARSAT system operates can be seen in Fig 2.

Figure 2. Overview of the operational procedure when an activated beacon uses COSPAS SARSAT [2].

Fig. 2 shows that when the EPIRB is activated, it sends a signal to a satelltie which is then relayed to the local user terminal and then sent to a mission control centre so thata search a rescue effort can be co-ordinated.

2. Aircraft System Installation Issues

When designing the ejection system, the location in which the system is installed influences the overall design of the system.

An inspection of a Boeing 787-8 and Airbus A320-200 has identified that the rear access hatch near the tail of the aircraft is a suitable location for EPRIB installation. This access hatch is located aft of the rear pressure bulkhead and is used for maintenance on the screw-jack for the elevator trim. The hatch itself is not load carrying and provides direct access to the EPRIB unit for maintenance and inspection.

Figure 3. Location of access hatch on 787-8 aft of the rear pressure bulkhead.

Fig. 3 shows the location of the non-structural access hatch relative to the rear of the aircraft. It can be seen that the hatch opens towards the front of the aircraft at approximately 90°. The size of the hatch which is approximately 400mm x 400mm is suitable to design the system around. However, consideration must be taken into how the ejection system is mounted to the access hatch considering the carbon fibre which the hatch is made from as well as the maximum distance which the hatch is able to open. Fig. 4 shows the same access hatch on the A320-200.

Figure 4. Location of access hatch on A320-200 aft of the rear pressure bulkhead.

Fig. 4 shows the location of the access hatch used for maintenance on the elevator-trim screw jack It can be seen that the hatch opens differently when compared to the 787-8 and at a greater angle when compared to the 787-8. The size of the access hatch is approximatelt 370mm x 370mm which is slightly smaller when compared to the 787-8 but is stil a suitable size for the system. If the system were to be designed for multi-aircraft compatability using both the 787-8 and A320-200 to determine constraints then dimensions of the A320-200 access hatch and the maximum angle that the access hatch of the 787-8 opens shall be used. The elevator trim screw jacks for both the 787-8 and A320-200 can be seen in Fig. 5.

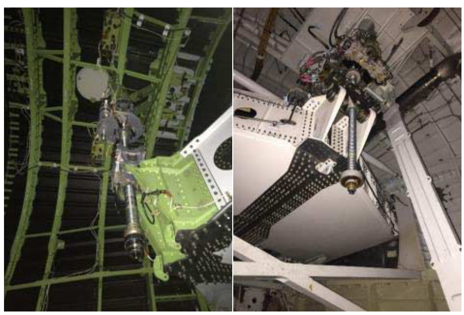

Figure 5. Elevator trim screw jack. Left 787-8. Right A320-200.

Fig. 5 shows the layout of the elevator trim screw jacks in both the 787-8 and A320-200 is almost the same. Because of the similarity between the two screw jacks across both the aircraft this simplifies the challenges associated with designing the ejection system for when maintenance work is required. Scheduled maintenance checks on the screw jack is designated as a B check meaning the check is conducted approximately once every six months. This means that the ejection system needs to be designed in a manner which takes this into consideration. From the physical inspection conducted on the aircraft, these locations will allow for the nautical technology of the EPRIB to be installed in aircraft in a manner which will not compromise its functionality and affect the performance of the aircraft.

3. Ejection System Concept Design

The complete design of the ejection system needs to consider how to protect the EPIRB after ejection and once it strikes the water as well as the force required to eject the EPIRB the sufficient distance.

The method to eject the beacon will involve a spring loaded system. The reason for this is that it removes a significant degree of complexity in regards to both regulations and functionality. Other methods such as explosives i.e. such as in an airbag will present a number of regulation problems and the use of systems such containing hydraulics or pneumatics will present a significant challenge in being able to operate independently of all other aircraft systems. As EPIRBs are not designed to withstand the high impact loads that ELTs experiences, the EPIRB will be contained within a protective capsule that will open immediately after ejection. The outside cover of the EPIRB ejection tube could be a plastic cover that is shattered upon ejection or a hinged cover that is automatically pushed open.

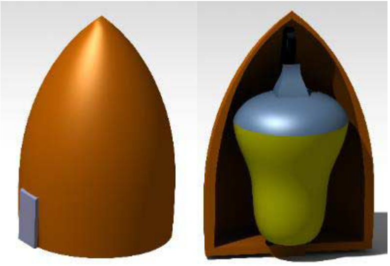

Figure 6. EPRIB protective capsule.

The EPIRB capsule in Fig. 6 is ballistic in nature. This design is intended to minmize the impact which the EPIRB will experience when it enters the water. To provide additional protection a shock absorbent material shall be included withinthe design which will surround the EPIRB minimzing the translational forces experienced by the EPIRB when the capsule enters the water. The mechanism to open the capsule shall be mechanically driven by being the spring loaded and shall activate once the capsule experiences a pressure which corresponds to a depth of 1 meter within the water. Open the capsule at this depth provides additional protection to the EPIRB as a depth of 10 meters will damage the EPIRB. This allows the EPRIB to float to the surface and activate undamaged. The capsule shall also allow a greater ejection force to be applied improving the functionality of the system. The EPIRB capsule contained within the ejection system can be seen in Fig 7.

Figure 7. Overview of the design system.

The design of the ejction system can be seen in Fig. 7. The total length of the system is 560mm and is 270mm wide. The overall size of the system is relaivly small and have been designed in a manner which should allow a relatively simple retrofit within existing aircraft. The overall mass of the system is heavily dependant upon the size of the spring with the size of the spring being dependant upon the force required to eject the system a pre-determined distance. To determine this distance the initial conditions need to be established. If the aircraft were in a nose dive, the EPIRB capsule needs to be able to clear half of the horizontal stabilizer span. Both the Boeing 747 and Airbus A380 have a hoizontal stabilzer span of approximately 22m, with the initial ejection distance required being set to 13m. As well as a displacement constraint a time constraint has been set for the EPIRB casing to travel to minimize the risk of it being struck by the horizontal stabilizer. The initial times range from 0.05s to 0.2s and as the EPIRB weighs approximately 0.6kg, the total mass of the casing plus the shock absorption material has been set from 0.9kg to 1.1kg. The calculated forces required to be generatedby the spring is shown in Table 2.

Table 2. Force requirements of the ejection system.

Mass	**0.9kg**	**1kg**	**1.1kg**
Time (s)	**Force Required (N)**	**Force Required (N)**	**Force Required (N)**
0.05	9360	10400	11440
0.1	2340	2600	2860
0.15	1040	1155	1271
0.2	585	650	715

Table 2 shows that the force requirements for the capsule to reach 13m in 0.05s is significantly higher than 0.2 seconds. Designing the spring to generate this force is ideal, although the mass required for a spring design that can generate this force may be unfeasible especially considering the ejection system is located a large distance rearwards of the center of gravity. Table 3 contains the principal characteristics for a number of materials which are used in springs, providing the necessary information to selects the most suitable spring.

Table 3. Principal spring characteristics [8]

Material/Specification	Elastic modulus, E, GPa (Mpsi)	Shear modulus, G, GPa (MPsi)	Density, ρ, kg/m^3 (lbm/in^3)	Maximum service temperature, °C (°F)	Principal characteristics
High-carbon steels					
Music wire (ASTM A228)	207 (30.0)	79.3 (11.5)	7840 (0.283)	120 (248)	High strength; excellent fatigue life
Hard drawn (ASTM A227)	207 (30.0)	79.3 (11.5)	7840 (0.283)	120 (248)	General purpose use; poor fatigue life
Stainless steels					
Martensitic (AISI 410, 420)	200 (29.0)	75.8 (11.0)	7750 (0.280)	250 (482)	Unsatisfactory for subzero applications
Austenitic (AISI 301, 302)	193 (28.0)	68.9 (9.99)	7840 (0.283)	315 (600)	Good strength at moderate temperatures; low stress relaxation
Copper-based alloys					
Spring brass (ASTM B134)	110 (15.9)	41.4 (6.00)	8520 (0.308)	90 (194)	Low cost; high conductivity; poor mechanical properties
Phosphor bronze (ASTM B159)	103 (14.9)	43.4 (6.29)	8860 (0.320)	90 (194)	Ability to withstand repeated flexures; popular alloy
Beryllium copper (ASTM B197)	131 (19.0)	44.8 (6.50)	8220 (0.297)	200 (392)	High yield and fatigue strength; hardenable
Nickel-based alloys					
Inconel 600	214 (31.0)	75.8 (11.0)	8500 (0.307)	315 (600)	Good strength; high corrosion resistance
Inconel X-750	214 (31.0)	75.8 (11.0)	8250 (0.298)	600 (1110)	Precipitation hardening; for high temperatures
Ni-Span C	186 (27.0)	66.2 (9.60)	8140 (0.294)	90 (194)	Constant modulus over a wide temperature range

Selecting the correct spring material is critical due to the temperatures which the aircraft will experience both at altitude and on a tarmac in the summer. This is because the system will not be subjected to environmental control as it is not located within the cabin. Additional to this, using a spring which meets the force requirements to eject the EPIRB over a certain distance is important. To determine this initial conditions needed to be established. If the aircraft were in a nose first dive, the EPIRB needs to be able to clear half of the horizontal stabilizer span. The horizontal stabilizer semi-span of both the Boeing 747 and Airbus A380 is approximately 22m, so the initial ejection distance required has been set to 13m. Additionally the EPIRB casing needs to be able to cover this distance in a specific time to minimize the risk of it being struck by the airframe. The time ranges from 0.05s to 0.2s. An EPIRB weighs approximately 0.6kg and the total mass of the casing plus shock absorption material is about 0.9kg to 1.1kg. The forces generated by the spring to meet these requirements are shown in Table 3. A combination of sensors and a number of different parameters have been proposed to determine system activation trigger. The conditions are described as follows.

- Altitude: The beacon must deploy at an altitude that results in it being located as close to the aircraft as possible. If the beacon deploys at too high an altitude, it may come to rest too far from the wreckage to be effective. If it deploys too low, it may become trapped in the wreckage and sink.
- Rate of descent: In the event of an uncontrolled crash landing, the rate of descent will be outside an acceptable range. Additionally, in the event of a controlled crash landing (i.e. engine failure) the rate of descent will vary from that when compared to a conventional runway landing.

To measure these parameters, the following sensors and hardware are required:

- Absolute pressure sensor: This sensor will measure the pressure relative to a perfect vacuum. It could be used to determine the sudden drop in pressure relative to a sudden decrease in altitude. A range of pressure values could be programmed to indicate that the aircraft is about to crash into the water.
- Differential pressure sensor: This sensor measures the difference between two pressures. Differential pressure sensors are able to measure sudden drops in pressure which will be able to indicate a sudden decrease in altitude.
- Control board: The control board will be used to analyse inputs from the sensors and assess when the system is required to activate for ejection. The conditions are met for activation the control board will provide an output to activate the ejection system.
- Battery: The battery is used to provide power to the system. The selected battery will be required to meet the power requirements of the system and be able to operate under a variety of environmental conditions.

Fig. 8 shows two different sensors which can be integrated within the ejection system.

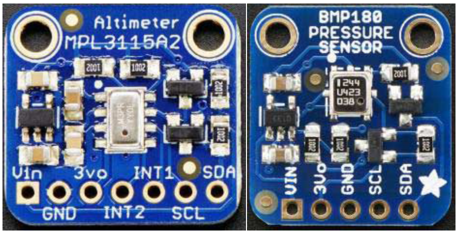

Figure 8. MPL3115A2 altimeter [16] (left), BMP180 pressure sensor [17] (right).

In Fig. 8, the MPL3115A2 on the left and the BMP180 are both barometric pressure, altitude, and temperature sensors. Both these sensors can be used to determine the altitude and the rate of descent which is being experienced by the system. The selection of the most suitable sensor depends primarily on power consumption and performance over a wide range of conditions. Both these systems are able to operate over a temperature range of -40°C to 85°C and have an accuracy of 3 pascals within 0.3 meters. The dimensions of the MPL3115A2 are 18mm x 19mm x 2mm and the dimensions of the BMP180 are 3.6mm x 3.8mm x 0.93mm. The size of these sensors mean that packaging them within the ejection system shall not be difficult. To maximize the effectiveness of the ejection system, it is critical that the system is 100% independent of all other aircraft systems and is able to effectively function no matter what the condition of the aircraft is and it is for this reason that hydraulics and pneumatics were not considered to power the ejection mechanism.

4. Store Release

Ejecting the beacon away from the aircraft prior to water impact to prevent it from being trapped in the wreckage is a key factor in being able to adapt the EPIRB from nautical to aviation purposes. Another concern is potential damage due to impact with the airframe. The dynamic and unpredictable nature of aircraft incidents means that it is extremely difficult to accurately model the scenarios which will be experienced. However some predictions can be made based on studies on store release.

An investigation by A. Cenko [14] discusses lessons learned over the past 30 years of store separation testing. Primarily for store separation testing the three approaches that have been used are Wind Tunnel Testing, CFD analyses and Flight Testing with significant advances having been made in all three areas in the past 30 years. The US Navy primarily relies on wind tunnel testing for new aircraft/store integration programs.

These studies analyze shapes which are more complicated than the EPIRB capsule and the analysis required for the EPIRB capsule is simplified as the primary concern for the EPIRB capsule is to determine its aerodynamic coefficients to provide the necessary information to predict the ejection process of the capsule a simplified dynamic analysis.

5. Conclusion

The aim of this project is to adapt a nautical EPIRB for aviation purposes to address the issue of tracking and locating aircraft which have crashed at sea. The feasibility of this project is considerable, as two key components critical to the operation of the system being the EPIRB and the COSPAS SARSAT satellite system are internationally accredited with their performance capabilities well established. From this study the following conclusions are made with respect to the design of an ejection system which allows for an existing nautical technology to be adapted for aviation purposes.

- The location of the retrofit is critical to minimize the impact on aircraft structural integrity and cost. The selected access hatch is aft of the rear pressure bulkhead and reduces the risk of the EPIRB being struck by the airframe after ejection. Using a non-structural component simplifies the certification process and a costly major re-design of that area is not required.
- The selected EPIRP for the project will be able to function as intended and not be negatively impacted by the changes in temperature which an aircraft experiences

during flight. The relatively small size of the unit makes it an ideal choice as to not only reduce the size of the ejection system but to minimize its weight contribution.

- Studies on store release have shown that the aerodynamic characteristics of a store upon release can be accurately predicted. This is useful as it reduces the cost of the project as costly wind tunnel testing is not required.

Based on the findings in this paper, adapting a nautical EPIRB for aviation purposes to address a search and rescue shortcoming is technically feasible. For general operator acceptance and practical implementation, costs associated with the system installation and certification, as well as the impact on aircraft systems and performance must be kept to a minimum.

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An Investigation into Conflict Resolution and Trajectory Prediction Aids for Future Air Traffic Control

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Abstract. The continuously increasing air traffic density has become a major challenge in air traffic control (ATC) due to the current ATC systems are approaching maximum capacity. To deal with the problem, an automated conflict resolution aid (CRA) and a trajectory prediction aid (TPA) have been proposed to serve as additional safety layers in the ATC systems. However, whether the proposed automation aids are worth to be applied in the current ATC workplace and could better support air traffic controllers (ATCOs) remain unknown. This study aims to investigate the effects of the proposed automations on ATCOs' workload and situation awareness (SA). To do so, twenty-four participants were evenly divided into two groups corresponding to the presence and absence of the TPA. In each condition, participants were instructed to perform simulated ATC tasks with the double of current air traffic load under the presence and absence of the CRA. The results showed that the CRA benefits ATCOs' workload and SA. The application of the CRA alone could benefit ATCOs while the presence of the TPA alone did not offer valuable benefits for ATCOs. Importantly, the CRA could lower the workload substantially when it was integrated with the TPA. The automation design aspect and its application in enhancing safety of future ATC are also highlighted.

Introduction

Safety of the future air traffic control (ATC) is compromised due to the continuous increase in air traffic density that is projected to be up to double in 2025 [1]. The nature of ATC tasks is tactical that includes the implementation of separation procedures for traffic collision detection and avoidance [2]. The execution of the tasks in the near future will be more challenging since current ATC systems are approaching maximum capacity and the current ATC practice may not be able to sustain the future air traffic [3].

To deal with the problem, automation has been suggested to be a practical solution. However, in the current systems, ATCOs are only provided with a conflict alerting system with a very short time allowance for the conflict resolution and have not been served with a conflict resolution automation. They still need to manually think of resolution maneuvers before the on-board traffic alert and collision avoidance system (TCAS) is activated (i.e. 45 seconds prior to the collision) while at the same time controlling other traffic aircraft [4].

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These facts clearly infer that ATCOs are in need of additional automation supports to deal with the imminent traffic growth particularly for conflict resolution and inferences of airspace information. The concepts of the conflict resolution aid (CRA) and the trajectory prediction aid (TPA) are proposed to be the additional layers for air traffic safety. However, the human-automation interaction safety critical procedures remain to be investigated before the actual implementation of the proposed automation supports. This paper presents the proposed automation concepts as well as the experimental evaluations of the concepts.

1. The concept of conflict resolution aid

The CRA is a form of automation that recommends an ATCO of a resolution maneuver. It provides a resolution advice two minutes prior to a conflict and applies the altitude-first resolver principle that suggests a vertical maneuver first over lateral and speed maneuvers due to its expediency [5] [6].

The CRA was developed with three design features. First, it implemented a "listing" style [7] that is the common presentation of the current ATC display. This is to enhance the familiarity and reduce the learning costs for new automation aids. Second, the CRA displayed an abbreviation of the established term of maneuvers in the existing ATC practice [8]. This allows for rapid understanding of the CRA advice since it complies with the present operational settings and less cognitive resources are required during the interpretation process [9]. Third, display clutter leading to costs on ATCOs' attention must be removed. Providing two different displays for the sustenance of understanding and planning tasks [9] is a plausible design solution for the CRA application. The example of the CRA advice is shown in Figure 1. The CRA advised aircraft SQC7069 to fly heading 30 degree and aircraft VLU203 to maintain at its current state.

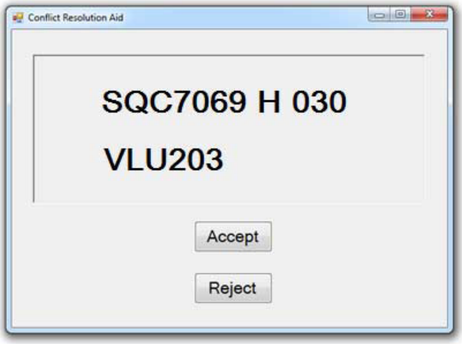

Figure 1. The Conflict Resolution Aid.

Our recent research examining a CRA [10] provided an empirical evidence regarding the benefits of conflict resolution automation. Although the CRA is a promising concept as an additional safety layer in ATC, however, ATCOs remain in need of comprehensive inferences of airspace information to perform other ATC tasks. The inferences of airspace information are currently obtained through the complex mental computation performed by ATCOs within a limited period of time based on the information on aircraft's data-tag. This fact together with the constantly increasing traffic would inevitably impose high mental workload on ATCOs. Hence, providing low-level automation which focuses on the information acquisition and analysis is also deemed necessary. By doing so, the information's inferences can be rapidly supplied to the ATCOs.

2. The concept of trajectory prediction aid

The trajectory prediction aid (TPA) is a low-level automation [11] that provides prediction of aircraft's states. It consists of the extrapolation of some future points based on aircraft's parameters including heading, altitude, and speed.

The design features of the TPA as shown in Figure 2 are described as follows. First, it adopts the proximity compatibility principle (PCP) [12] where a relevant task or mental operation should be provided adjacently in perceptual space through information-processing linkage. In this study, the waypoints of the aircraft's route are displayed to increase the processing-linkage with the primary radar display. Second, the "detail on demand" principle [13] is implemented such that ATCOs are able to only allocate their cognitive resources to respective aircraft that require controlling actions. Third, providing contextual information [14] regarding all aircraft's parameters will allow ATCOs to have the freedom in selecting relevant for any particular situation.

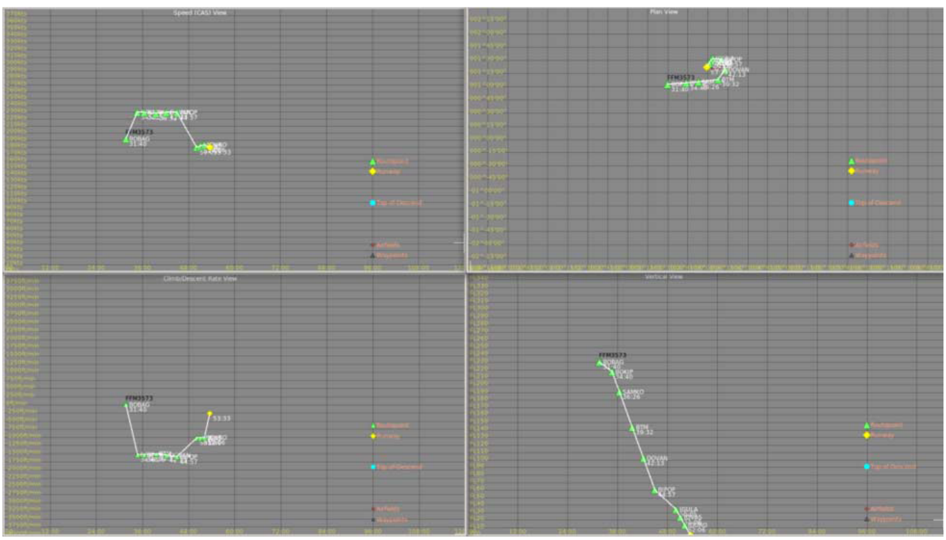

Figure 2. The Trajectory Prediction Aid.

There are four different TPA parameters that are examined in this study including plan view, vertical view, climb/descend rate view, and speed view that show the predictions of the lateral and longitudinal positions, the altitude profiles, the climb and descend courses, and the speed profiles of an aircraft along the time axes, respectively. All the four parameters were displayed with the expected times of when an aircraft will be passing the waypoints (as indicated by the triangles) and landing on the runway (as shown by the rhombus).

3. The experiment

To further investigate into the application of the CRA and the TPA for future ATC operation, a laboratory-based experiment was conducted to examine the effects of the automations on ATCOs' workload and situation awareness. There were six hypotheses tested in this study:

H1. The CRA would lower ATCOs' workload.
H2. The CRA would enhance ATCOs'SA.
H3. The TPA would lower ATCOs' workload.
H4. The TPA would enhance ATCOs' SA.
H5. There would be interaction between the CRA and the TPA on ATCOs' workload.
H6. There would be interaction between the CRA and the TPA on ATCOs' SA.

3.1. Methods

3.1.1. Participants

Participants in this study consisted of twenty one (21) ATCOs from the Civil Aviation Authority of Singapore (CAAS) and Singapore Air Force (SAF) and three (3) students with ATC knowledge and experience through prior ATC training. Their ages ranged from 23 to 62 years (Mean = 29,63 years, SD = 8.32 years). ATCOs' average work experience was 4.45 years.

3.1.2. Apparatus

The NLR Air Traffic Control Research Simulator (NARSIM) [15] that applied the standard instrument departure (SID) and standard arrival routes (STAR) of Singapore airspace was used. One ATCO's position and two pseudo-pilot's positions were set in the experiment. Four monitor screens were provided for the ATCO's position to show the primary radar, the flight progress strips data that contains aircraft's update, the CRA (Figure 1) and the TPA (Figure 2), respectively. Three monitor screens including the primary radar (Figure 3), the blipper inputs for the observation of flights' status as well as for the maneuvering inputs, and the CRA feedback displays were placed for the pseudo-pilots' position.

If the resolution advice given by the CRA was accepted by participants, it would be sent directly to the pseudo-pilots and the pre-programmed maneuvers would be implemented. If the advice was rejected, the pseudo-pilots would not receive resolution maneuvers from the CRA and need to wait for ATCOs' own resolution maneuvers. For the TPA, ATCOs were able to pinpoint on respective aircraft to obtain the details about the aircraft's current and future courses by clicking the aircraft call-sign on the display panel to activate the required information.

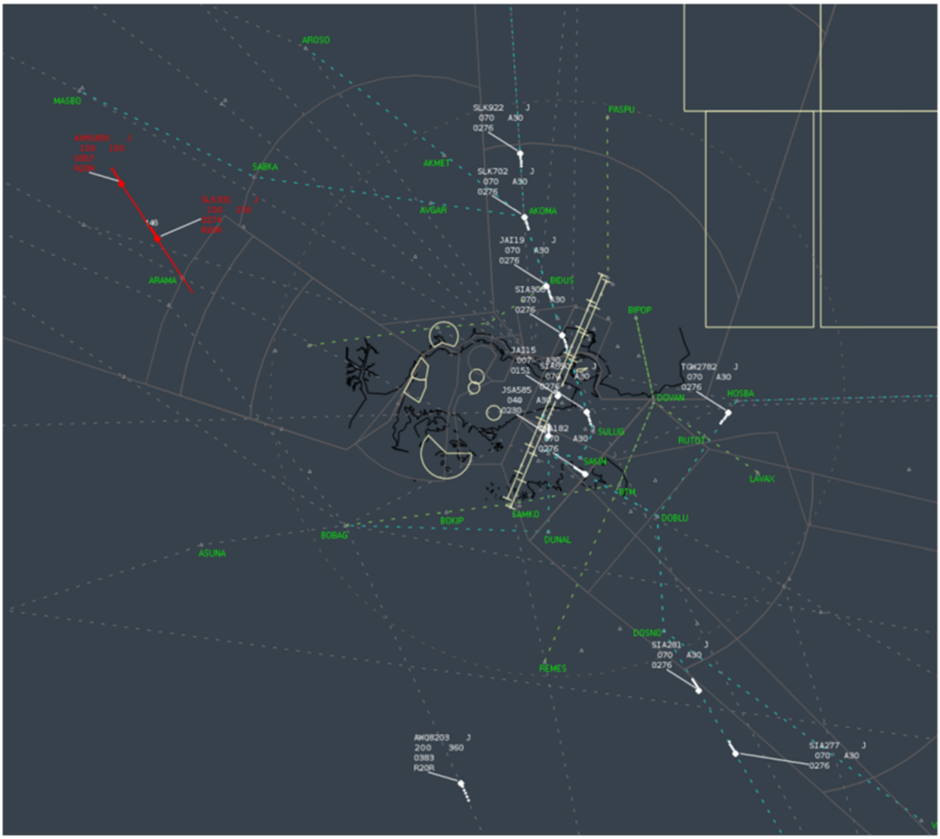

Figure 3. The Primary Radar Display.

3.1.3. Experiment design

The factors of interest in the present study were CRA and TPA conditions. The CRA and TPA conditions were within- and between-subjects factors, respectively. Each factor consisted of two levels: presence and absence of automation. All the participants were randomly assigned to the two TPA levels. The sequence of CRA level was counterbalanced using crossover design to remove any carry-over effects.

When the CRA was available, the CRA provided correct maneuvering advice to all designated conflicts. In the absence of the CRA, participants performed the conflict resolution task manually. In both CRA levels, there was a conflict alerting system that highlighted a conflicting aircraft pair in red. Participants could perform other ATC tasks including monitoring and controlling with the aid of the TPA when it was present but they needed to perform the ATC tasks manually when it was absent.

3.1.4. Procedure

A laboratory-based experimental was performed to examine the concepts of the CRA and the TPA. A one-hour briefing and training session was provided to the participants. During the experiment, the participants were requested to perform ATC tasks that included controlling traffic flow and maintaining separation with the traffic density of 60 aircraft, representing double of the current air traffic load. The participants were responsible for aircraft within their controlled area and were allowed to utilize the automation aids when available. The communication between the participants and the pseudo-pilots were verbal through voice transmission. Upon receiving the instructions from ATCOs, the pseudo-pilots inputted the commands to the ATC simulator.

Participants were also instructed to respond to the real-time SA probes throughout the experiment using the Situation Present Assessment Method (SPAM). They were stimulated to respond to the SA probes if their attentional resources were available. After each experiment sessions, the participants were requested to complete the set of subjective rating for mental workload.

3.1.5. Analysis

A 2 (CRA conditions: CRA vs No CRA) x 2 (TPA conditions: TPA vs No TPA) mixed-design ANOVA was performed for the workload and situation awareness (SA) measures, respectively. Targeted t-test analysis was performed for the significant interaction found earlier in the omnibus analysis.

The workload measures included subjective and objective workload measures. NASA-TLX (ranging from 0 to 100) [16] was used to measure subjective workload. SPAM's ready response latency and percentage of timeouts were used to measure objective mental workload [17]. The SA data were derived from SPAM's probe response latency and percentage of correct responses [18].

3.2. Results

3.2.1. Workload

The workload rating (Table 1) was lower with the CRA than without it, $F(1, 22)= 10.67$, $p= <0.01$. Significant interaction effect between the CRA and TPA conditions on workload ratings was found, $F(1, 22)= 5.58$, $p= 0.03$. The t-test revealed that the TPA integrated with the CRA could substantially lower the workload, $t(11)= 3.74$, $p= <0.01$. Supporting the workload rating, marginally lower objective workload was observed with the CRA as indicated by the lower percentage of timeout (Table 2), $F(1, 22)= 3.89$, $p= 0.06$. There were no other significant results.

Table 1. Mean Workload Ratings (SE in parenthesis).

	CRA	No CRA
TPA	60.67 (3.75)	72.45 (2.85)
No TPA	71.28 (2.87)	73.17 (3.19)

Table 2. Mean Percentage of Timeouts (SE in parenthesis).

	CRA	No CRA
TPA	21.70% (4.78%)	31.48% (4.38%)
No TPA	26.92% (6.51%)	29.82% (5.37%)

3.2.2. Situation awareness

Higher SA was found with than without the CRA, as indicated by higher correct responses to SA probes (Table 3), $F(1, 22)= 10.61$, $p= <0.01$. Consistent with the SA probe accuracy, the effect of CRA on SA probe latency (Table 4) was significant, F(1, 22)= 6.54, p = 0.02, showing higher SA with than without the CRA. The CRA and the TPA interaction on SA probe latency was significant F(1, 22)= 4.91, p= 0.04. The t-test result further showed that when the TPA was absent, the SA latency was longer when participants were not equipped with the CRA, t(11)= 2.59, p= 0.03. There were no other significant results.

Table 3. Mean Percentage of Correct Responses (SE in parenthesis).

	CRA	No CRA
TPA	57.41% (4.08%)	43.52% (4.27%)
No TPA	60.25% (5.86%)	50.54% (6.09%)

Table 4. Mean Probe Response Latency (SE in parenthesis).

	CRA	No CRA
TPA	11.75s (1.12s)	12.27s (1.38s)
No TPA	9.35s (0.56s)	16.64s (1.65s)

Collectively, the findings are presented in the model with the hypothesized relations as shown in Figure 4.

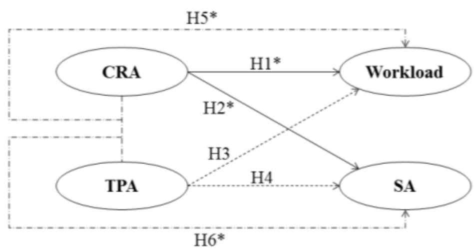

Figure 4. The experiment results (* indicates significant effects).

3.3. Discussion

3.3.1. Effects of conflict resolution automation

The introduction of an additional safety layer that goes beyond alerting ATCOs of a predicted conflict to recommending a conflict resolution maneuver appeared to show positive effects on ATCOs' workload and SA to deal with the imminent traffic growth. ATCOs showed lower workload with the aid of the CRA, supporting H1. This improvement was reflected in both subjective and objective workload measures. The CRA was found to help reduce the cost on ATCOs' mental computation for the conflict resolution process as indicated by the lower subjective workload that is related to a task's overall cost for a human operator [19]. This was further supported with the objective workload reduction throughout the experiment where ATCOs showed better responses to other tasks.

ATCOs' SA was also improved with the CRA showing that H2 was upheld. The resolution maneuvering advice provided by the CRA helped ATCOs to highlight the conflict situation and the solution thus minimise the demand on processing resources [10]. Since the prediction of intervention's consequences [20] could be processed more rapidly using the CRA, ATCOs' SA that includes the perception, comprehension, and projection of airspace environmental status [21] was benefitted from it. Collectively, the CRA was found as a promising concept for enhancing safety of the future ATC.

3.3.2. Effects of trajectory prediction aid

The current ATC work place has not been equipped with a TPA. In the existing practice ATCOs have to rely on their mental calculation of aircraft's future points utilizing the data of its heading, speed, and altitude that are only provided on the data-tag. In the present study, the TPA was evaluated and four aircraft's parameters were provided including plan view, vertical view, climb/descend rate view, and speed view. Prominently, our results showed that the presence of the TPA did not benefit ATCOs' workload and SA.

The results in this study revealed no workload reduction with the aid of the TPA, showing that H3 was not supported. However, the TPA did not compromise the workload either. These findings might be explained by the fact that ATCOs did not really rely on the TPA. ATCOs opted not to make use of the TPA particularly for routine tasks that were perceived as manageable for them. However, a higher but not significant workload rating with the TPA could be reflective of the extra workload imposed to monitor another separate TPA display [22].

Similarly, SA was neither improved nor decreased with the TPA, indicating that H4 was not upheld. This finding was particularly surprising since the TPA was expected to increase in knowledge related to the airspace inference thus increasing SA. However, associated with the workload finding, underutilization of the TPA might also explain the SA finding. ATCOs preferred to rely on their own cognitive resources to process the airspace information and to perform other tasks including responding to the SA probes. This study, however, did not find adverse effects of the TPA on SA.

Prior studies in command and control context revealed inconsistent findings about providing information for human operator during tasks performance. There were three main effects of information availability on ATCOs. First, providing information that supported tasks execution was beneficial for operator [14, 22]. Second, providing tasks-relevant information negatively affected operator's performance [23] . Third, as what has been found in this study, contextual information did not affect tasks execution. These inconsistencies triggered a need to further investigate the application of the TPA.

3.3.3. Integration of conflict resolution and trajectory prediction aids

This study failed to show the benefits of the TPA on ATC operations when it was implemented alone. However, when it was integrated with the CRA, there was a substantial reduction on the workload, supporting H5. This finding suggested that the TPA could provide additional feedback for ATCOs on what the automation (i.e the CRA) was doing [24]. The feedback was beneficial for ATCOs because an automation's action is hardly understood by operator and is likely to be mediated by a display [25]. Being able to understand the CRA, whether it could do its task reliably, helped ATCOs to calibrate their dependence on the CRA, thus lowering their workload.

Furthermore, along with the substantial workload reduction, no evidence of forfeited SA was found due to the integration of the CRA and the TPA. Furthermore, ATCOs' SA was lowest when they performed the task manually without any automation supports. In contrast with [23], this finding showed that providing task-relevant information together with the automation aid that processed similar airspace data as the provided information, helped ATCOs in maintaining their SA.

3.3.4. Practical implication and limitation

This study has positive implications for the implementation of the automation aids. First, the results revealed that the CRA benefits ATCOs' workload and SA. This implied that a conflict resolution automation is worth investing for future ATC work place. However, the application of the TPA alone did not offer valuable benefits for ATCOs, although the integration of the TPA with the CRA could substantively reduce ATCOs' workload. Hence, it is advisable for system designers to look for the application of either the CRA only or integrating it with the TPA for the future ATC systems.

There exist some limitations in the present study. First, the ATC simulator used in this study was a medium fidelity simulator, environmental factors such as weather were not considered during the simulation. Second, conflict resolution is often related with conflict detection. Although this issue is not addressed in this paper, misses and false alarms related to a conflict alerting system should be taken into account during the development and the application of the CRA.

Still, the design principles of the automation aids highlighted in this study offer direct implications for the safety layers in the future ATC. The findings presented in this study also outlined the worth investing ATC infrastructures.

4. Conclusion

This paper investigated some automation aids as additional safety layers that are relevant to the design for future ATC systems. Specific design features for the proposed automation aids were described. Experiment-based evaluations provide empirical evidences of the benefits and costs of the automation aids. The application of the CRA with the design features elaborated upon within this study certainly supported the users. Furthermore, the integration of the CRA and the TPA was found to markedly reduce ATCOs' workload, thus aiding ATCOs in sustaining the imminent traffic growth.

Acknowledgment

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Measuring Compliance During Aircraft (Component) Redeliveries at KLM Engineering & Maintenance

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Abstract. Aircraft and aircraft components are redelivered to the next operator or owner during the phase-out process. During this process the operator is required by law and contract requirements to show compliance with maintenance procedures. At KLM E&M the phase-out documentation process is under increasing scrutiny as the number of aircraft phase-outs is assumed to rise in the coming years. The compliance process is investigated in order to measure, analyze and improve compliance with regard to maintenance data and record keeping during aircraft (component) redeliveries. For this purpose a benchmarking study is conducted to identify process bottlenecks. This study proved that in the case of KLM E&M phase-out, Landing Gears Life Limited Parts (LG LLPs) form the major bottleneck. Subsequently, an aircraft compliance model is developed to support the compliance cycle. As a case study, the documentation of LG LLPs of KLM's Boeing B737 aircraft fleet is investigated in this research. LG LLPs which are most frequently interchanged and installed on the nose gear miss the highest percentage of documentation necessary to prove back-to-birth traceability (a traceable history of a component over its life), which is a necessary feature from a phase-out perspective. On the basis of the compliance model and the observed data, several improvements to the phase-out process are proposed.

Keywords. Aircraft maintenance, phase-out, traceability

Introduction

Aircraft record keeping is a complicated process, involving thousands of parts, subsystems and systems as well as multiple interactions with these parts over aircraft life – typically ranging from 30 to 40 years. Furthermore, record keeping and storage involves a variety of physical and digital locations (e.g. hangars, line maintenance stations, workstations, tablets, paper-based print-outs, etc.), and involves many stakeholders. Each stakeholder may have a different perception and priority concerning the documentation process. Managing the diversification of data and records, where thousands of paper files, output from a variety of IT systems and even microfilms are involved, can prove to be costly and time demanding.

During aircraft phase-out, defined as the handover of an aircraft (component) to a subsequent owner, it is necessary to prove to the authorities and the next owner that all necessary operational and maintenance activities have been performed correctly, or have been duly rectified if not performed correctly. In other words, *compliance* with regulatory provisions and business standards is a must. During the phase-out process many sections, departments and divisions are involved, because during the service life of an aircraft it receives maintenance in different places [1], as recorded by various paper-based or software systems under the banner of Product Lifecycle Management, or PLM [2,3,4]. The operator is required by the competent authorities to redeliver the aircraft (components) in an airworthy state, as regulated by national aviation authorities (e.g., the European Aviation Safety Agency (EASA) for large parts of Europe). Furthermore, any contractual (lease) requirements associated with an aircraft should be complied with during hand-over. To prove compliance, it is necessary to keep records of all performed activities, and to retrieve and show these documents upon phase-out to the next owner. However, retrieving all the necessary documents is considered to be a very difficult, inefficient and time consuming task.

The goal of this paper is to analyze the current process of aircraft record collection during phase-out and to propose a documentation compliance model to assist in the phase-out process. This requires definition and identification of waste in the current compliance process, modelling of this process as well as validation of this model via analysis of a specific phase-out example, which also highlights specific improvement opportunities. The remainder of this paper follows this basic structure.

1. State of the art in phase-out compliance

Aircraft phase-out processes are, to the best of the authors' knowledge, not covered by existing scientific literature. No specific methods are available to model, analyze and improve the phase-out process of an operator. As such, for the purpose of thoroughly investigating phase-out compliance, the Define-Measure-Analyze-Improve-Control (DMAIC) method from the Six Sigma process improvement methodology is adopted [5]. In applying DMAIC to the phase-out problem, specification of the involved data and records, representation of the current process and benchmarking of its performance are involved, as discussed in the next sections.

1.1 Specification Maintenance Data & Records

In general, a maintenance provider is responsible for generating and storing the vast majority of documentation related to proof of compliance with respect to continued airworthiness of an aircraft. As such, a maintenance provider needs to comply with regulations from the relevant aviation authority (e.g., the European Aviation Safety Agency (EASA)). Furthermore, requirements from the operator (current owner or lessor of the aircraft) as well as any requirements of a lease company (potentially the current owner, in case of lease constructions) must be respected. Therefore the variety of documents at aircraft (component) redelivery is considerable high (see Figure 1). This figure clearly shows the variety and size of document gathering and controlling during the phase-out process. At KLM Engineering & Maintenance, the standardized list of document categories (note: not individual documents!) approaches 100 in number.

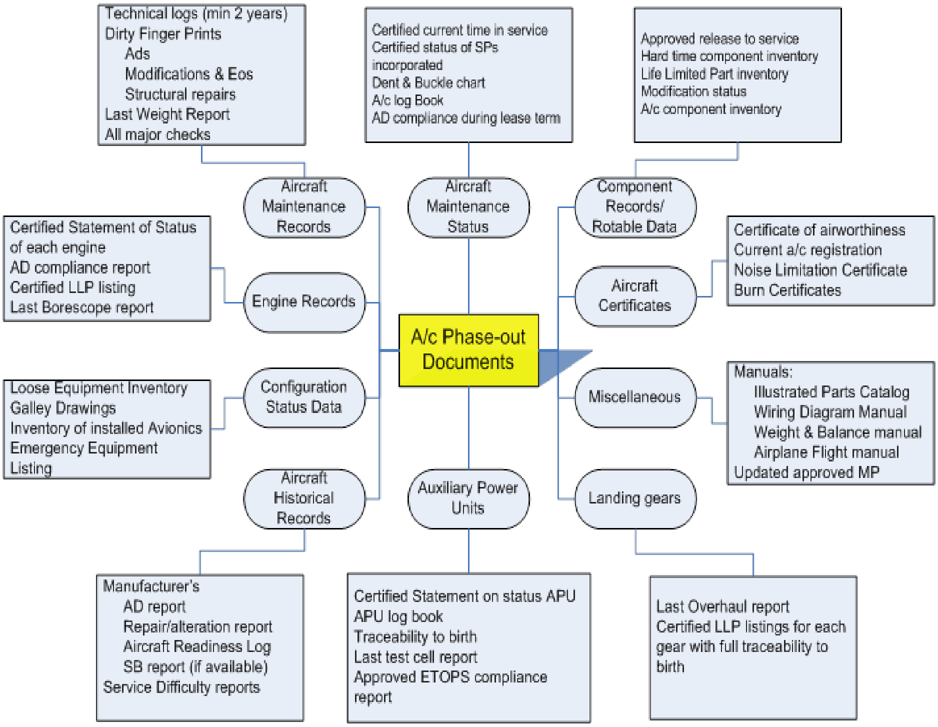

Figure 1. Aircraft phase-out documentation and records.

1.2 Consolidation Phase-out process

The current phase-out process has been reconstructed from existing procedures. Furthermore, estimates of phase-out process duration have been derived from in-house project reports. Table 1 clearly shows that the entire process takes about 33 weeks and is divided into 8 different steps [6]; data for this table has been compiled by considering the average time traces of 18 individual phase-out projects. Each of the 8 phase-out process steps are analyzed. Step 1, 2 and 3 are routine steps: These are performed at the start of each AC redelivery project and take up to 12 weeks. This long period of time can be explained somewhat by an illustrative example. Consider that for the phase-out of a 20-year old Boeing 737, the following is required:

- Approximately 200 boxes of paper (80,000 pages of hard copy documents) of data and records are received by the Phase-out Team. Eventually only about 36 boxes will be handed over to the next operator or owner after documents filtering and controlling.

- Most of the boxes are in Iron Mountain (Static Archive E&M). At this moment there are about 20,000 boxes of E&M data in the static archive present.

- Also documentation should be gathered from different local archives, such as from the Landing Gears Department, Engine Services, Aircraft Structures Department and other.

Table 1. Phase-out process steps and duration.

Phase-out process step	Avoidable	Routine	Duration	% of total time
1 Requesting phase-out data		**X**	**4 weeks**	12%
2 Collecting phase-out data		**X**	**4 weeks**	12%
3 Controlling received data		**X**	**4 weeks**	12%
4 Sorting out received data	**X**		**8 weeks**	24%
5 Searching missing documents	**X**		**5 weeks**	15%
6 Final preliminary data set		**X**	**1 weeks**	3%
7 Handing over data and solving open issues	**X**		**6 weeks**	18%
8 Final updates phase-out data		X	1 weeks	3%
Total	**3**	**5**	**33 weeks**	**100%**

Given the large amount of data, the number of departments involved as well as revenue-generating functions and parallel phase-out activities performed during the first three steps, the 12 week time set for requesting, collecting and receiving cannot be significantly shortened. Steps 1, 2 and 3 are considered routine steps and the time used in these steps cannot be considered avoidable.

Following step 3, the aircraft will be grounded and is not allowed to make more flights. This implies that from step 4 onwards, all the steps of the process should be performed as quickly as possible, but the reality is that step 4 is the longest step (see Table 1). One can furthermore observe in Table 1 that steps 4 and 5 are about sorting out the received data and searching for the missing documents. If the received data is correct and no documents are missing, these steps would not have to be taken; therefore these steps are considered as Avoidable. Similarly, step 7 can be avoided if the data which is handed over contains no mistakes and incomplete documents. The daily reality is that the steps 3, 4 and 7 take the most time and are the most labor intensive ones. Table 1 also shows that about 57% of the time spent by the Phase-out Team is Avoidable.

2. Aircraft Phase-out Compliance Model

Given the previous findings, there is a necessity to construct a model of the current phase-out process, as well as its to-be counterpart, to achieve savings with respect to the avoidable (wasteful) process steps. In this section, construction of an Aircraft Phase-out Compliance Model is discussed. The building blocks of the model are given in Figure 2, where the model depicts the compliance cycle.

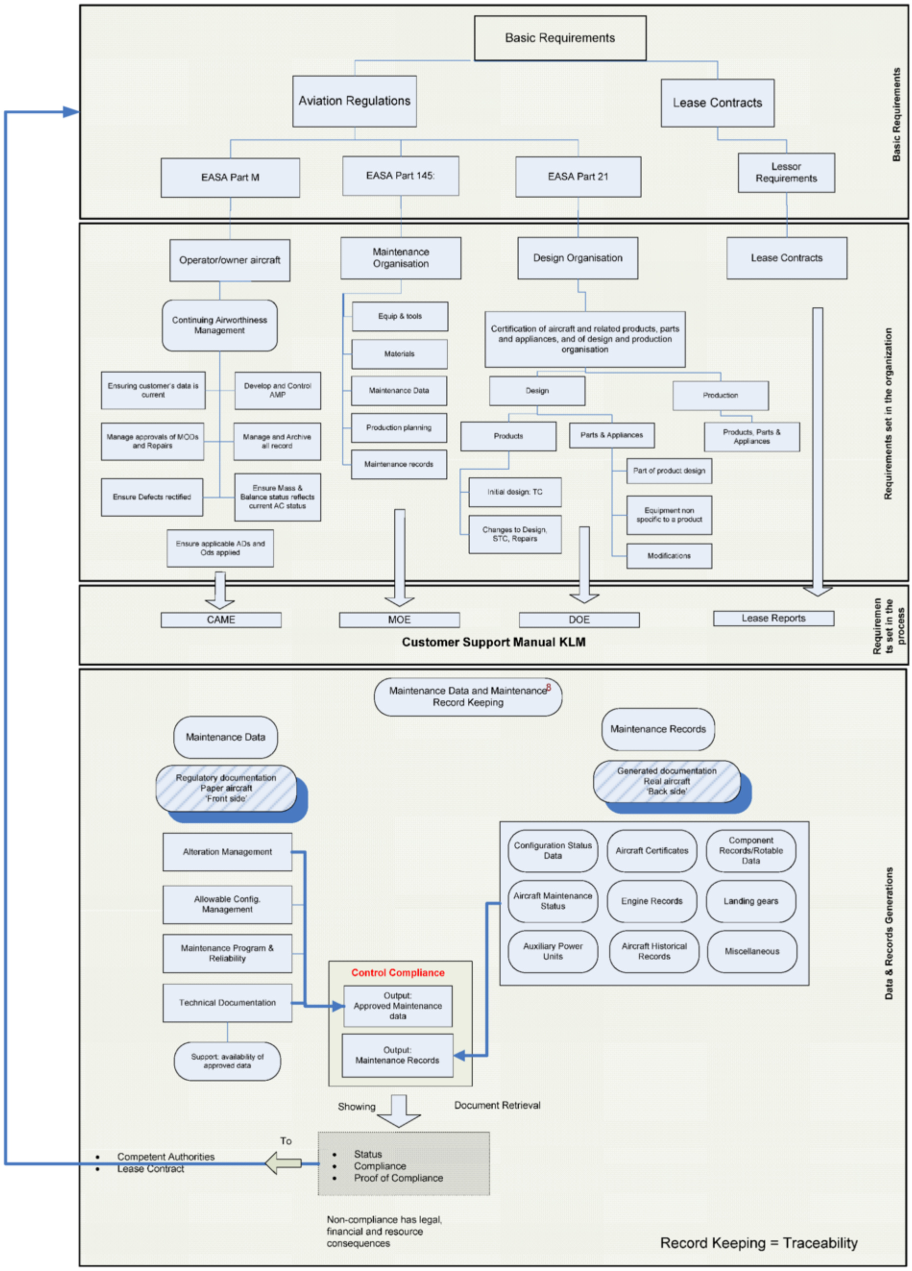

Figure 2. Aircraft Phase-out Compliance Model.

Four main building blocks can be distinguished: 1) basic requirements coming from regulators and/or lease companies, as stipulated contractually in the latter case; 2) organizational requirements derived from the different organizational roles involved in operating and maintaining the aircraft (as represented by the operator, maintainer and design organizations); 3) process requirements – which are specific to the process implemented by the organization running the phase-out process; 4) data and record generation, which deals with the actual data and records being generated over the aircraft life on the one hand, compared to the legislative and design-required documentation on the other hand. A full match of approved maintenance data (the output of the regulatory side of documentation) with maintenance records (the output of the generated operational aircraft documentation) is sufficient for showing formal proof of compliance, which is the necessary end state of the phase-out process from a documentation perspective.

The Aircraft Compliance Model can be used in any maintenance organization; however it should be modified in order to depict the organization's compliance cycles. In the next section, a case study concerning documentation of landing gear Life Limited Parts (LLPs) is considered, where the object of study is a representative aircraft subsystem necessitating phase-out proof of compliance at times of hand-over.

3. Landing gear phase-out case study

During redelivery of landing gear LLPs, compliance with law [7] and lease contracts should be performed. First of all it is essential to find out about the means and records which the Landing Gears Department has available to comply with the requirements. The right part of Figure 3 shows these documents and records. On the left side the documents and records which are required according to the law and market. During the extensive analysis of the Landing Gears data measurements the quality of the available documentation is investigated.

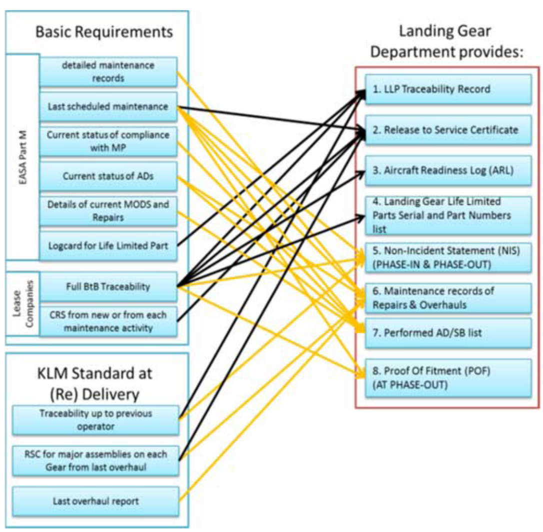

Figure 3. Landing Gear compliance – requirements and records.

The Landing Gear Department has eight documents available to prove the airworthiness of a Life Limited Part specific to a Landing Gear. These are briefly explained below:

1. **Life Limited Parts Traceability Record:** This is one of the most extensive and elaborated document. Various information and details about the specific LLP are stated in this document
2. **Release to Service Certificate:** This document is explicitly required by Aviation Regulations. EASA Part M.A. 803 (a) states: "A Certificate of Release to Service shall be issued at the completion of any maintenance carried out on an AC component." As stated earlier, major Landing Gear Maintenance at E&M is performed by vendors. Therefore every time a component or a complete Landing Gear receives maintenance and is considered airworthy again, a Release to Service Certificate (RSC) must be provided.
3. **AC Readiness Log:** This is an official hard copy document which the operator has to have in its archive. It is one of the Original Delivery Records which is provided by the OEM to the operator.
4. **Landing Gear Life Limited Parts Serial and Part Numbers list:** This is an official hard copy document which the operator has to have in its archive. It is one of the Original Delivery Records which is provided by the OEM to the operator.
5. **Non-Incident Statement:** This statement which is signed and stamped by KLM states that during the operational life time of the component within KLM no major incidents have occurred where the specific component was involved. However, this document is not regulatory required, but it is only provided upon request by KLM to the Lease Company or next operator.
6. **Maintenance records of Repairs & Modifications of the most recent work performed:** Examples are Dirty Finger Prints of the maintenance provided to a LLP.
7. **Performed AD/SB list:** This is a list of performed Airworthiness Directives or Service Bulletins, the ADs and SBs are performed as Central Engineering Orders (CEOs))
8. **Proof Of Fitment:** If a component of a Gear has been changed separately, in other words not at the standard Time Between Overhaul (TBO), then at redelivery of the Gear the next operator or Lease Company demands a Dirty Finger Print(DFP) of the maintenance task which the component received during the maintenance job. If the operator cannot provide that specific DFP, then the AC will be inspected and a statement will be signed by the inspector in order to prove the specific components' fitment was according to the standards. This statement is called Proof Of Fitment and is provided by the operator to the customer at the time of Gear redelivery.

The arrows in Figure 3 show the connection between the basic requirements and the available documents of the department. These arrows show the available resources of the department to comply with the rules and requirements. There is however a distinction between the eight documents of the department: the number 5 up 8 can only be required at Gear redelivery. The first 4 documents are needed to show that the current status of the component is according to rules. This difference is illustrated with the black and orange colors of the arrows. Therefore, by controlling the first four documents of a LLP one can find out about its traceability.

In the following sections, quantitative analysis is carried out with respect to specific landing gear LLPs. There are in total 97 different LLPs [8] which account for 8481 individual parts. Analyzing the documents of in total 8481 components is not feasible, therefore the available information about the components is used to choose such samples that they would give a good indication of the complete documentation quality of the all the components.

In Figure 4 some indicative results are presented based on the installation position and price of the measured LLPs. One can see that LLPs which are installed on the Nose Gear of B737-300/400 have the poorest documentation. The Main Gears of the 300 and 400 types come on the second place.

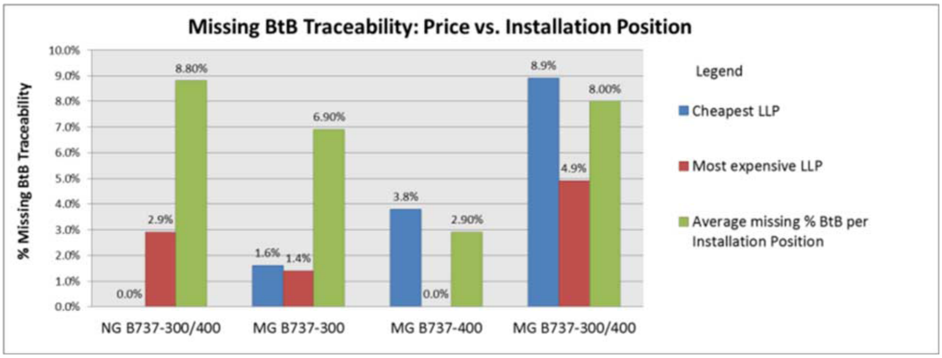

Figure 4. LLP installation position versus missing documentation for nose and main landing gears (NG; MG).

Results are also categorized based on the frequency of interchangeability. As Figure 5 shows, the LLPs with the highest frequency of interchangeability (18 months) have the poorest documentation; hence, miss the highest percentage of documentation which can prove traceability of the Lease Contract Requirements.

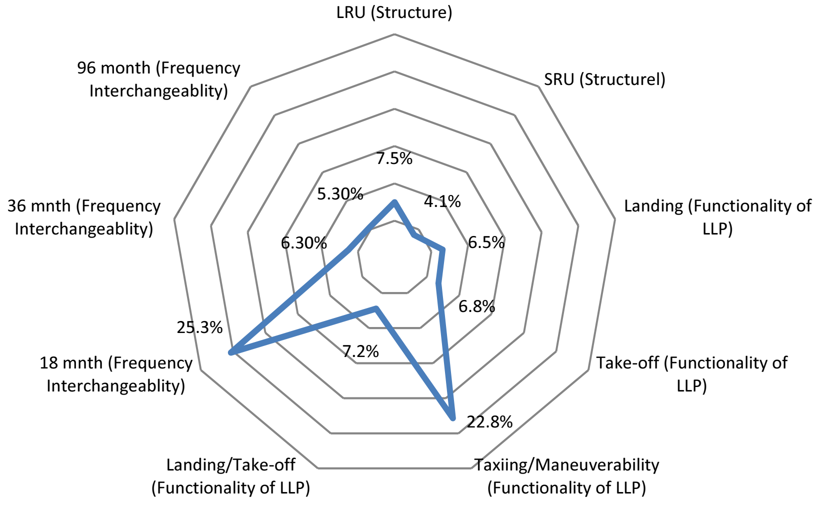

Figure 5. Frequency of interchangeability versus missing documentation.

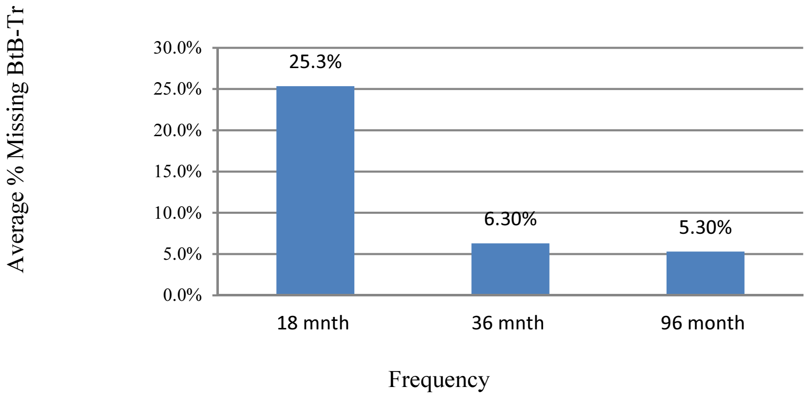

Figure 6. interchange frequency against average missing documentation.

Figure 6 shows a summarized overview of interchange frequency versus missing documentation. Notably, components which are interchanged more often (18 months) miss most documentation compared to the ones which are interchanged less often (36 or 96 months).

4. Conclusions

A generic model to identify aircraft phase-out requirements, associated record keeping and resulting compliance (or lack there-of) has been introduced in this paper. Though some steps have been abbreviated or omitted because of confidentiality, application to a landing gear case study shows the ability to identify documentation requirements and quantify shortcomings in documentation at phase-out.

Recommendations for future research include further testing and validation of the proposed model for more aircraft (sub)systems, as well as providing more detailed guidelines for translation of regulatory and operational requirements to documentation generation. Finally, the capability of the model to suggest areas for improvement in current phase-out process must be highlighted in further research. Though the model has been used within this research for this purpose, aspects of confidentiality prevent wider dissemination of these recommendations. Future research should alleviate this.

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Decision Analysis of Stakeholder Views in the Design of Steel Structures in Fire

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Abstract. This paper demonstrates how decision-making techniques can be used to balance diverse stakeholder views, especially engineers from multiple disciplines, toward approaching suitable fire engineered solutions for steel structures. Forty-two fire design stakeholders were interviewed for their opinions on selecting a suitable fire protection for structural steel buildings. The stakeholders compared and rated decision attributes. Their views were assessed using the Group-Analytic Network Process (G-ANP). The results show the priority trends from aggregated fire design stakeholder views and systematic ranking of the fire protection options toward suitable decision-making thereby highlighting the viability of the decision analysis techniques for transdisciplinary collaboration in structural fire design.

Keywords. Fire design stakeholders, fire protection products, steel structures, collaborative decision-making, G-ANP.

Introduction

Transdisciplinary collaboration will typically entail the coming together of knowledgeable individuals or stakeholders from multiple disciplines committed to achieving the same goals. An example is in the performance-based design of buildings where the collaborating design stakeholders flexibly apply alternative solutions to meeting design objectives. However, conflicting views, available time and methods to achieve a suitable consensus among stakeholders impede such collaboration [1]. Pertinently, the end point of establishing a common ground among stakeholders is 'decision-making' and the 'analysis' of the stakeholder conflicting views plays a central role in such decision-making.

The destructive impacts of fires on society define the need for structural fire safety in the design of buildings. Different fire safety design strategies have evolved from lessons learned from real incidents and research studies [2]. The structural stability of buildings in fires is most important in the fully-developed stage and will necessitate the fire resistance of structures to prevent collapse of all or part of the building, collapse onto and/or fire spread to neighboring property, adverse effects on fire-fighter operations and environmental damage.

There are many ways of achieving fire resistance of structures; one way is to apply passive fire protection products (FPP) such as intumescent paints, sprayed on cement-

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based or mineral fiber material, gypsum plasterboards or alternatively to optimize the design and leave the structure unprotected. However, the conflicting views of the multiple fire design stakeholders, e.g. architects, structural and fire engineers etc., involved in deciding on the most suitable approach pose design uncertainties. For instance, cement-based sprays are adjudged as cheap fire protection products [3]; hence, a building owner having a low budget for structural fire protection may prefer this option. The architect and structural fire engineer may not support the use of a sprayed on option on the basis of poor aesthetic appeal, paucity of skilled manpower for its thorough application and the probability of being compromised in a pre-fire event e.g. earthquakes. Following this, the architect may recommend intumescent paint toward expressing building aesthetics.

In some steel structural fire design decision scenarios the preference of any fire protection product may be influenced by the criticality of achieving building regulation approval, which may depend on fire risk assessment (i.e. identification of inherent fire risk prior to design); ensuring minimal adverse effect on fire-fighting operations and maintainability of the product. These varying stakeholder views, the flexible fire design approach and the interdependencies of design decision attributes demands a balanced collaborative decision-making process in achieving structural fire safety. This process will manage inherent design uncertainties toward mitigating delays and loss of productivity.

To address the fire design stakeholder decision-making problem this paper firstly gives an overview of the Group-Analytic Network Process (G-ANP) methodology. Then by applying a summarized G-ANP technique and benefit-cost network models it demonstrates the capability and adaptability of the technique to account for various dependencies and interdependencies of proposed design decision attributes. This is evident from the balancing of varying views from forty-two nominated fire design stakeholders under a general collaborative structural fire design decision-making approach.

1. Overview of the ANP

Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) [4, 5] are multi-criteria decision analysis techniques stemming from operation research and management science. These techniques have been widely applied in diverse decision-making problems characterized by conflicting decision criteria, multiple decision-makers, independence and dependencies of the decision attributes and competing options. A great many decision analysis techniques exist, such as: Data Envelopment Analysis (DEA), Weighted Sum and Product Models (WSM and WPM) etc., and their application is dependent on the peculiarity of the decision-making problem. For instance, the application of WSM and WPM is most suitable for solving decision-making problems having homogenous criteria, e.g. costs-only or benefits-only decision problems [6]. The AHP and ANP are considered appropriate because selecting a suitable steel structural fire protection product may consider costs, benefits and other attributes in analyzing the problem.

AHP breaks a decision problem into components and linearly structures the decision components in a sequence of a goal at the top-level, decision criteria and sub-criteria at mid-levels and the competing options at the bottom level as shown in Figure 1(a). The loop under the ‘options’ component in the AHP structure indicates that the elements in the component are independent. AHP employs a fundamental pairwise or relative comparison scale [7] to elicit judgements from decision-makers (experts) on decision attributes with respect to a stated decision goal. The hierarchical sequence of the AHP also depicts the aggregation, synthesis order and outcomes from the application of the technique. Hence, in the application of AHP a goal must be stated. The decision attributes are deemed as independent and analyzed as such. A detailed summary of the six basic steps has been presented elsewhere [8] as well as applied to a pilot study prior to the present study.

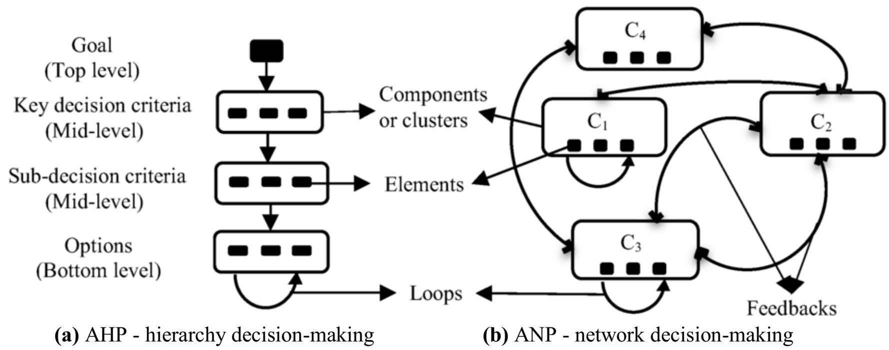


Figure 1. Decision analysis structures: (a) AHP, (b) ANP, [9].

The Analytic Network Process (ANP) is a generalization and extension of AHP [5] whereby possible interactions or influences between dependent and interdependent decision attributes in complex decision problems can be assessed. Therefore, ANP is built within the concept of 'influence' to give decision-maker/s the opportunity to go beyond the top-down AHP-approach in decision-making processes. A decision problem in the ANP is structured as a network as shown in Figure 1(b) to represent two kinds of dependencies within and outside decision clusters (i.e. C_1 – C_4). The connections from one cluster to the other are referred to as outer dependency, while the loops represent the inner dependency of elements in the same cluster e.g. C_1 and C_3. Feedback also exists in the network representing interdependencies between elements in two different clusters e.g. C_2 and C_3. ANP has been widely applied in solving complex decision problems such as in supplier evaluation process, [10] and market share assessments [7]. A dictionary and detailed application of ANP can be found elsewhere [9]. The application of ANP is briefly summarized in the following seven steps:

Step 1. Given a decision goal and attributes, determine the control network consisting of control criteria within benefits, opportunities, costs and risks (BOCR merits).

Step 2. Design control criteria network structures with appropriate clusters, elements and their dependencies.

Step 3. Construct cluster matrices per control criteria network and determine cluster weights using the fundamental scale [7], AHP pairwise comparison and prioritization [8].

Step 4. Reapply the scale, pairwise comparison and prioritization to derive influence priority scores of elements based on their dependencies; the consistency of all paired judgements must be checked based on the AHP theory [4].

Step 5. Construct supermatrices and enter the influence priority scores in the initial supermatrix, weight the supermatrix with the cluster weights derived in Step 3, generate the limiting supermatrix by raising the weighted supermatrix to large powers until elements on each row converge to identical values.

Step 6. Normalize the limiting priority scores and add them up to determine preference scores of the decision attributes; do Steps 4-6 for all considered BOCR merits.

Step 7. Synthesize the preference scores from the decision merits with the appropriate mathematical ratio [e.g. benefits (Bi)/costs (Ci) ratio] to rank the competing options.

Importantly, the key aspect of eliciting suitable judgements from decision-maker/s when applying ANP Steps 3 and 4 is the use of the fundamental pairwise comparison scale [7] and asking the fundamental ANP question:

Given a critical element (cluster, criterion, sub-criterion) and comparing elements A (cluster, criterion, sub-criterion) and B (cluster, criterion, sub-criterion) under it, which element has more influence on the critical element?

To explain the ANP supermatrices in Step 5, consider the clusters in the decision network, Figure 1(b), as C_p, p = 1, 2,…, m and consider each cluster as having n_p elements, denoted by $s_{p1}, s_{p2}, \ldots, s_{pm_n}$, then Figure 2(a) represents the decision network's supermatrix. A typical entry block, W_{ij} of the network supermatrix is shown in Figure 2(b).

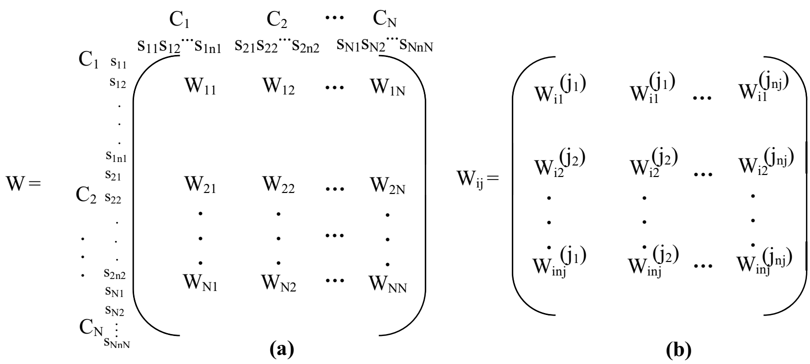


Figure 2. ANP entry-matrices: (a) network supermatrix, (b) network sub-matrix, [9].

Here, the Eigenvectors that make up the columns of this sub-matrix are the influence priority scores derived from decision-makers' paired comparisons; where W_{ij} is the principal Eigenvector depicting the influence of elements in the i^{th} cluster on the elements in the j^{th} cluster. Zero is entered for elements with no influence in the supermatrix [5] on the premise that elements cannot influence themselves. In weighting the supermatrix to generate the limiting supermatrix each column block is multiplied by the corresponding cluster weight to make the supermatrix column stochastic i.e. each column in the supermatrix adds up to unity.

1.1. Collaborative group decision-making

The key interest in collaborative decision-making is to achieve group consensus [11]. There are different factors and ways to achieve group consensus in transdisciplinary collaboration such as stakeholders' commitment to frequent group face-to-face meetings and brainstorming sessions [1]. However, this may be considered time consuming, onerous and will need a technique to speedily and transparently establish group consensus. A group decision-making technique known as Geometric Mean Method (GMM) was introduced as an adjoining component to AHP which aggregates the judgements of multi-decision-makers [12]. GMM represents the average ratio of each category of pairwise comparisons. When the decision-makers are considered as having unequal influence on the decision-making process and given appropriate individual weights, GMM is then referred to as Weighted Geometric Mean Method (WGMM). The application of GMM with the AHP is the same with ANP, given that ANP is built on the AHP, whereby the pairwise comparison judgements from several decision-makers are also aggregated to derive influence priority scores that are entered into the ANP supermatrix. The viability of GMM has been demonstrated elsewhere [13] in aggregating individual judgements and priorities in group decision-making and it is mentioned that the decision-makers agree to act as a group for the common good of solving the decision problem and are treated as a 'new individual'. Therefore, individual priorities may not matter but inconsistent judgements can be checked and revised. GMM or WGMM is applied at ANP Step 4. The WGMM equation for the aggregation of individual judgements is given as:

$$Z_g(a,b) = \prod_{p=1}^{n} Zp(a,b)^{w_k} \tag{1}$$

where:

- Z_g (a,b) is the geometric mean of the group judgements on the relative importance of the 'elements' *a* & *b*.
- Z_p (a,b) is individual *k*'s judgement of the relative importance of 'elements' *a* & *b*.
- w_k refers to the weight of individual *k* i.e. $\sum_{k=1}^{n} w_k = 1$; *n* is the number of decision-makers.

More explanation on WGMM can be found elsewhere [13].

2. Stakeholder decision analysis

The goal for the multi-stakeholder decision analysis is *"to select the most suitable fire protection option for steel structures for destructive fires"*. This is formulated from a general perspective of steel structural fire design without reference to any specific design scenario. Two control networks are considered on the merits of benefits and costs. The benefits and costs key decision criteria (components or clusters) and their respective sub-decision criteria (elements) are identified from literature [14-16] and classified for this study as shown in Table 1. Four applied fire protection products (FPP) are assessed for steel structures based on single-element design, they are:

Intumescent paints (ITP), board systems (BST), concrete encasement of steel (CES) and sprayed on cement-based material (SCM).

Another option considered for investigation is *unprotected steel (UPS)*. 'Structural system design' is not investigated as this may require the combination of the listed FPP as fire protection design options, which is beyond the scope of this paper. The probable influences of the decision attributes in Table 1 were determined by a structural fire design expert panel and used to model the ANP network structures by connecting dependent/interdependent clusters with linking arrows. These network structures guide the decision analysis. Figure 3 shows the benefits control network model for this work.

Based on ANP Steps 1-3, ANP network models, pairwise comparison scale [7] and fundamental ANP question (Section 2), pairwise comparison judgements were extracted through structured interviews from 42 experienced stakeholders within reputable organizations in New Zealand. The nominated fire design stakeholder categories and rate of individual participation is as follows:

Building owners (2); building insurers (1); construction engineers (3); structural engineers (3), fire engineers (7); environmental engineers (3), architects (2), manufacturers/suppliers (1), building consent authorities (3), fire service personnel (9) end users (4) and others (4).

Table 1. Structural fire design key and sub-decision criteria (clusters and elements).

Costs control criteria	**Sub-decision criteria (elements)**
Economy cluster	Constructability (CA) Business continuity (BC) Profit-making (PM) Minimum material use (MMU) Maintaining supply chain (MSC) Financial risk management (FRM)

Benefits control criteria	**Sub-decision criteria (elements)**
Safety cluster	Fire risk assessment (FRA) Structural fire resistance (SFR) Pre-fire building resilience (PF1) Clarity in design details & specs (CDD) Fire-fighting operations (FFO) Fire spread beyond compartment (FSC) Maintainability (MA)
Environmental cluster	Environmental sustainability (ES) Environmental act compliance (EAC)
Societal Cluster	Building aesthetics (BA) Human comfort (HC) All stakeholder involvement in design (ASI) Building regulation approval (BRA) Building use and features (BUF) Health and safety (HS) Post-fire building resilience (PF2)

In the benefits network model (Figure 3), it can be observed that there are assumed inner dependencies among elements in the *safety, environmental* and *societal* clusters as represented by the loops and these clusters also have interdependencies with the *fire protection products* (FPP) cluster represented by the two-way arrows between them.

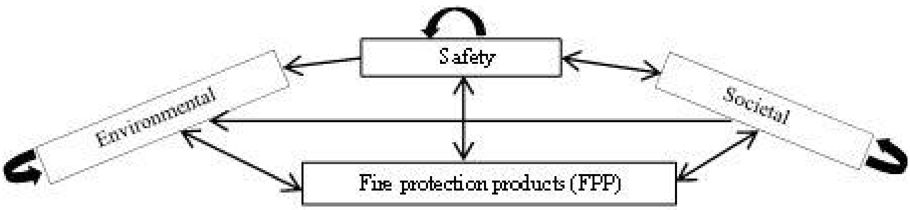


Figure 3. ANP-benefits control network model.

The one-way arrows from *safety* and *societal* clusters to the *environmental* cluster indicate that the elements in the former clusters influence the later cluster (i.e. outer dependence). Cluster weights [7] (e.g. Table 2) were determined based on the interactions in the network models. From Figure 3, the elements in the FPP cluster are not inner dependent and so this is given a zero influence weight in Table 2. Zero is also entered for the 'environmental' cluster where it has no outer influence on the 'safety' and 'societal' clusters. The 'costs' network cluster weights were also determined but not shown here.

Table 2. ANP-benefits cluster weights.

	Safety	Environmental	Societal	FPP
Safety	0.4162	0.0000	0.0625	0.3333
Environmental	0.0587	0.5000	0.0625	0.3333
Societal	0.1089	0.0000	0.4375	0.3333
FPP	0.4162	0.5000	0.4375	0.0000

From the extracted stakeholder judgements, given *safety* cluster element influence on *building regulation approval* (BRA) of the *societal* cluster i.e. outer dependency, Table 3 shows the judgement matrices of the two participant architects (AT1 and AT2).

Table 3. Architects judgements of some safety cluster element influence on building regulation approval: (a) judgement matrix from AT1 (b) judgement matrix from AT2.

BRA	FRA	PF1	FFO	MA
FRA	1	3	3	4
PF1	1/3	1	1	2
FFO	1/3	1	1	2
MA	1/4	1/2	1/2	1

BRA	FRA	PF1	FFO	MA
FRA	1	5	1	2
PF1	1/5	1	1/5	1/4
FFO	1	5	1	2
MA	1/2	4	1/2	1

AT1 in Table 3(a) judged *fire risk assessment* (FRA) as somewhat more influential than *fire-fighting operations* (FFO) on BRA and rated FRA as 3 in the top row of the matrix; consequently, FFO is somewhat less influential than FRA, hence it is rated as the reciprocal value of 3 (i.e. 1/3) in the column on the left of the matrix. The same paired comparison process is carried out in Table 3(b). Here AT2 judges FRA and FFO as equally influential on BRA, which differs from AT1's judgement. This shows the varying stakeholder views in a decision-making process. Based on the AHP theory, '1' is retained for paired comparison of an element against itself, which completes the judgement matrices. Due to limited space, the judgement matrices of other participants on the various relative influences are not shown here.

To establish group consensus for the stakeholders, this paper considered the influence level of stakeholders in ANP Step 4. The fire design stakeholder categories are weighted and their weights used in aggregating their relative judgements. The stakeholders can weight each other or elect a supra-stakeholder to weight them if they are brought together during the group decision-making process. Here it was not possible to bring the 42 stakeholders together given their diversity and geographical location. Hence, published professional fees of building design stakeholders [17] are normalized and applied on the assumption that their consultation fees depict their input/influence in a design decision-making process. The determined stakeholder weights (w_k) add up to unity and are:

Building owners (0.183); building insurers (0.037); construction engineers (0.029); structural engineers (0.183); fire engineers (0.111); environmental engineers (0.073); architects (0.212); manufacturers/suppliers (0.015); building consent authorities (0.007); fire service personnel (0.007); end users (0.018); and others (0.125).

WGMM (Equation 1) is then applied, Table 4(a) shows the aggregated judgment matrix of AT1 and AT2 from which the influence priority scores and a consistency ratio are derived and presented in Table 4(b). The priority scores sum-up to unity and the consistency ratio of the architects' judgement is 0.001, which is within the consistency limit of 0.10 [4]. The same aggregation, prioritization and consistency process is applied to other fire design stakeholder category individual judgements' which completes ANP Step 4.

Table 4. Aggregated judgement and derived influence priority scores from AT1 and AT2:

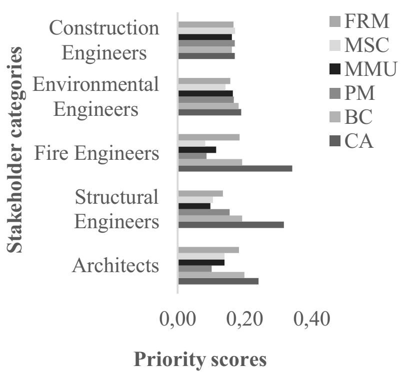
(a) Aggregated judgement matrix

BRA	**FRA**	**PF1**	**FFO**	**MA**
FRA	1.00	1.78	1.26	1.55
PF1	0.56	1.00	0.71	0.86
FFO	0.79	1.41	1.00	1.34
MA	0.64	1.16	0.75	1.00

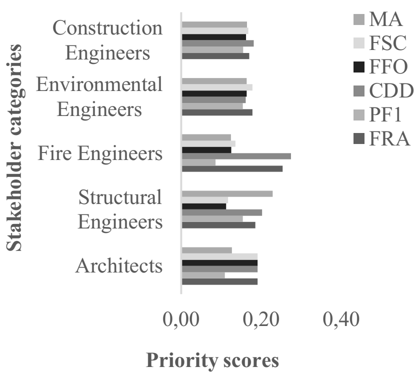
(b) Influence priority scores

Scores
0.33
0.19
0.27
0.21

The influence priority scores derived from the aggregation of each category of stakeholder judgements help the fire design stakeholders to view the relative influence or importance level of the decision elements to their decision. For instance Figure 4 shows the participant engineers and architects' priorities, given the relative dependence of structural fire resistance (SFR) on elements in same safety cluster with respect to the benefits control criterion and outer dependence of board systems (BST) on economy cluster elements with respect to the costs control criterion.



(a)



(b)

Figure 4. Stakeholder priority trends: (a) economy influences on BST, (b) safety influences on SFR.

Figure 4(a) shows that the architects, fire and structural engineers' highly prioritized *constructability* (CA) in selecting the BST fire protection product. In Figure 4 (b), it is observed that for the construction and environmental engineers, all safety elements relatively influence SFR in selecting a fire protection product. However, the structural engineers' view is different as they highly prioritized *maintainability* (MA) and *clarity in design details* (CDD). Fire engineers highly prioritized *fire risk assessment* (FRA) in comparison with other engineers. This demonstrates the viability of G-ANP in eliciting conflicting multidisciplinary views, aggregating them to show the various influencing decision-makers' priorities.

The ANP synthesis (Steps 5-7) toward ranking the competing fire protection products were applied as listed and explained in Section 2. The aggregated influence priority scores from the 42 participant stakeholders were input in their appropriate cluster column blocks in the initial supermatrix and weighted with their respective cluster weights. The limiting priorities in this example converged to row-identical elements at the 6th power of the weighted supermatrix. The ANP synthesis is completed with the normalization of the limiting priority scores and the ranking of the competing options is plotted in Figure 5 based on the benefit-cost ratio.

"Unprotected steel (UPS)" has the highest benefit-cost ratio and it is the top-ranked fire protection option from the stakeholder decision analysis. However, this may not be the case in a structural system design of a specific steel building. The decision-maker/s opinions in such design scenario will be reflected in the synthesis and ranking of design options.

The application of G-ANP in the decision analysis example has provided valuable information to approach a suitable decision as observed in Figure 5; here the decision-makers may opt for the 2nd or 3rd-ranked option (CES or BST) on the basis that a consideration of the costs outweighs the benefits in their final decision. ITP and SCM are 4th and 5th ranked options and may be chosen if the decision-makers have an overwhelming interest in them regardless of their high cost and low benefit implications respectively.

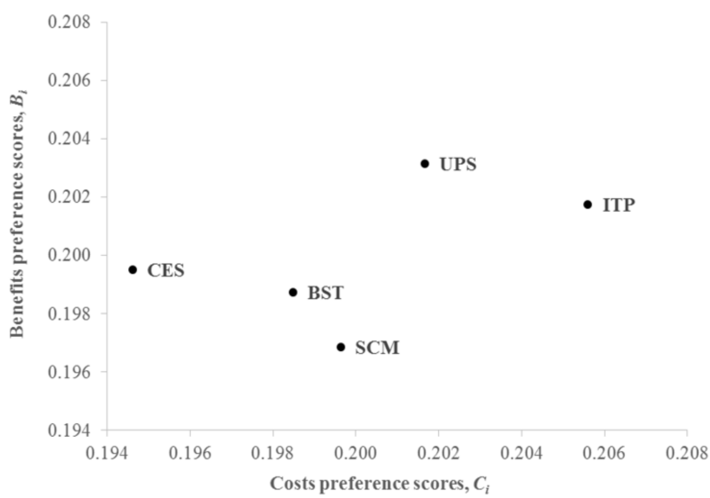


Figure 5. Benefits vs costs preference scores and ranking of the fire protection options.

3. Conclusion

The G-ANP applied in the structural fire design decision-making example has demonstrated its viability and adaptability, given the seamless aggregation of individual views from 42 fire design stakeholders, the transparent synthesis of interdependent decision attributes and ranking of the competing options toward suitable decision-making. Having successfully applied these techniques in a complex decision-making problem, G-ANP is recommended to balance divergent views and varying goals of multiple decision-makers in many collaborative transdisciplinary engineering environments.

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Using Web Mining and Perceptual Mapping to Support Customer-Oriented Product Positions and Designs

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Abstract. In recent years, many e-commerce websites provide consumer feedback functions and social networks, allowing customers to share their purchasing and usage experiences online. Companies collect and analyze information from customers' reviews through the platform to understand the customers impressions of the products they purchased. Online customer reviews has been widely regarded as an important source of information influencing customers buying decisions. In addition, online customer reviews help companies to redesign their products with key features that better positions to target customers in promising market sectors. This research uses online customer reviews as the business intelligence (BI) corpus. After determining the source webpage of customer reviews, a web crawler is needed to collect customer review text. Afterwards, computer-assisted text mining, clustering analysis, and perceptual mapping are applied to develop a formal methodology to compare similar products in a given domain. In this research, the consumer electronic sector is studied. Mobile phone customer reviews are web crawled, collected, mined, and analyzed. The study assists mobile phone manufacturers to understand the voice of customers in both positive and negative perspectives of post-purchasing experiences. The customer-preferred product functions, hardware/software/app features, and price positions, as key business intelligence, are derived for new product designs and market launches.

Keywords. Web crawling, Web mining, Clustering analysis, Perceptual map, Market positioning

Introduction

According to the report of Internet World Stats in November 2015, there are more than three billion Internet users in the world, which account for 46% of the world population [1]. As e-commerce grows, more and more people purchase products through the Internet [2]. E-Marketer, an independent market research company, predicted that business-to-consumer (B2C) e-commerce sales worldwide will reach about $1.9 trillion in 2016 and increase about 13% compared with 2015 [3]. In addition, the emergence of advanced shipping and payment options influences the growth of B2C e-commerce

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sales, while major brands now are actively exploring new international markets that leverage online rapid channel fulfillment and transactions [4].

Online shopping create emerging business opportunities. Companies are competing to create more effective Internet business processes. As the e-commerce websites mature, they provide user-friendly interfaces for customers to place an order, pay for products, and track the order. When customers receive the products, e-commerce websites provide a review platform for customers to share their shopping experience. As a result, sellers are able to analyze the customer's experience, which facilitates the use of customer feedback to redesign products or services in adapt or create products which meet expectations. When customers are satisfied with their products, they will be more willing to trade with the seller again [5]. On the other hand, potential customers can also use the review platform to determine whether the product meet their choice criteria [6].

In order to let customers write down genuine comments reflecting their post-purchase experience, many e-commerce websites allow customers who have already purchased products submit reviews. An open and anonymous space to express satisfaction and dissatisfaction provides a less biased report of the purchase process. Online customer reviews have been widely regarded as an important element in the customer decision-making process [7]. Furthermore, online customer reviews affect potential customers' perception of products and influence the sales of product [8].

To understand the customer's experience, companies collect numerous customer reviews to search for information that can be used to create and maintain strategic advantage by monitoring the value proposition. This research collects e-commerce customer reviews by using a web crawler. After data compilation, customer reviews are mined, clustered and analyzed. Then, the research use perceptual maps to compare the capability and pricing of competitor's products. The difference of many product reviews can be observed via data visualization. This research develops a way to help companies efficiently understand the voice-of-customers and guide strategic decision making to re-design products and make new product prices. The paper is organized as follows. Section 1 reviews and discusses the background literature. The methodology and case implementation are described in Section 2. Finally, the concluding remarks are provided in Section 3.

1. Literature Review

In this section, the literature related to web crawling, text mining, cluster analysis, and perceptual mapping are discussed.

1.1. Web crawling

Web crawlers are a system which seek specific web page data to download and are one of the main components of web search engines. Web crawlers aggregate massive numbers of web page data through the Internet for later processing by web search engines. The data are indexed and the downloaded pages are identified by hyperlinks. Therefore, users can efficiently find the web pages which match the queries using web search engines. Web crawlers are used for a variety of purposes. Some periodically collect large sets of web pages and save the data for posterity [9]. Web data miners use web crawlers to collect data for statistical analysis [10].

Researchers collect data from web pages to analyze customer purchase data or reviews. Bross acquires hotel reviews from Tripadvisor.com and digital camera reviews from Amazon.com, Epinions.com, and Buzzillions.com to extract and detect product aspects described in customer reviews [11]. A web crawler is used to collect customer purchase data from www.gonsen.co.kr and analyzed customer demographic variables and segment customers by lifestyle [12]. Xiang et al. obtain customer reviews from Expedia.com with a web crawler to explore the relationship between hotel guest experience and satisfaction [13].

1.2. Text Mining

Text mining is frequently as a means to structure and automatically detect information such as trends from unstructured text [14]. Text mining can extract valuable information and guide organizations toward effective solutions [15]. There are several components to text mining including text segmentation, summary extraction, stemming, keyword identification, topic detection, taxonomy generation, term clustering and document categorization. With these components, unstructured text documents are transformed into knowledge [16].

People using the Internet to leave a history of their personal shopping experiences, product views and often write opinions. These online usage trails help researchers to understand the consumer behavior of customers which improves current products or services. Customer reviews and store advertising are collected from three American pizza stores on Facebook and Twitter and text mining is used to explore the customers' emotions and responses from advertising [17]. Researchers use text mining and content analysis to explore the determinants of customer satisfaction for hotel reviews [18]. Digital cameras reviews are collected from Testfreaks.com and a rule-based approach system and text mining are used to extract and identify critical product features [19].

1.3. Cluster Analysis

Clustering is a common method for statistical data analysis, which groups similar objects into the same cluster without pre-definition. The objects in a cluster are very similar to one another and very different from the objects in other clusters [20]. It is a type of unsupervised machine learning, which is used to derive the structure of the data sets and does not require labelled training data or any pre-assumptions [21].

Clustering algorithms often divided into two categories, including partitioning methods and hierarchical methods. The process of partitioning methods generates a single partition of the data in an attempt to recover natural groupings of the data sets. Partitioning clustering includes k-means, k-medoids, k-mode, and genetic k-means algorithm (GKA). Hierarchical methods are characterized by the tree structure which establishes the course of the analysis. There are two approaches used for hierarchical methods. One is agglomerative and the other is divisive. Hierarchical clustering includes Ward's method, balanced iterative reduction and clustering using hierarchies (BIRCH), and clustering using representatives (CURE) [22].

1.4. Perceptual Mapping

The concept of product positioning was presented in early 1972 which is an important element of marketing strategy. Product positioning is affected by several factors such as product characteristics, consumer characteristics, company's marketing strategy, competitors, and customer perceptions [23]. Product positioning is used to identify the customers' view of product and assists companies in comparing their product with competitors' products. Companies implement new marketing strategies to achieve a desired market position [24].

A perceptual map is used with product positioning to depict customer perceptions and product characteristics (e.g., product price, quality, attribute rating). Perceptual mapping helps to visualize consumer perceptions of product alternatives. Companies identify the market gaps and explore alternative designs using perceptual mapping [25].

2. Methodology and Case Demonstration

The methods used in the research are mentioned in this section. The research applies web crawling, mining and perceptual mapping to collect and analyze e-commerce feedbacks as customers' post-purchasing experiences. Thus, customer-oriented product positions and design improvement using updated online customer reviews can be implemented. There are five formalized steps in the research including data collection via web crawling, data preprocessing, text mining, clustering analysis, and perceptual mapping.

In the data collection process, the online customer reviews are used as raw data. The target e-commerce website and product are selected as the case product and the data is retrieved by the web crawler and exported to a database. Low meaning words and phrases are deleted in the data preprocessing and the text mining technique is applied to extract key terms. Clustering analysis devides the customer reviews into groups that are meaningful or useful. Finally, perceptual mapping visualizes cunsumer perceptions of product alternatives.

2.1. Data collection

In the research, the customer reviews of Amazon.com were used as the data source. Amazon.com was chosen because it is the most popular e-commerce website, which represent a large sample of online EC customers. Besides, Amazon.com restricts and verifies that the purchase reviews can only be keyed into the systems by customers who have purchased specific products at Amazon. After selecting target website, the research selects ASUS ZenFone2 (type: ZE551ML) mobile phone as a specific product in the case study. The customer reviews pages addressing ZenFone2 post-purchasing opinions are used as the web content for analysis. In the customer reviews page, the research captured customers' review date, stars, title, and opinion text using the web crawaler tool, WebHarvy (2016). This research collected 1,914 ZenFone2 customer reviews which were writen during May 18 to November 4, 2015. All extracted data are exported by WebHarvy to a CSV-file for further text mining and subseqent analysis.

2.2. Data preprocessing

After the data collection process, low meaning words and phrases are deleted. For example, in Amazon, if a customer does not write the review title, the system automatically uses the customer star level (e.g., five stars or four stars) to fill in the review title field. Therefore, the research deletes these characters. The customer reviews are divided into positive and negative reviews using established rules. In this study, four and five stars reviews belong to positive reviews. On the other hand, one to three stars reviews belong to negative reviews. In addition, if a review mentions both pros and cons, the research divides the review into positive and negative reviews.

2.3. Text mining

This research uses the statistical software R to extract the key terms in both positive and negative reviews [26]. The data must be preprocessed including word segmentation, stop words removal, and stemming. Second, calculate the normalized term frequency-inversed document frequency (NTF–IDF) of each terms. After that, delete the terms which are low meaning and select the key terms by sequencing the value of NTF–IDF. This research selected 150 key terms of each positive and negative reviews.

2.4. Clustering analysis

After selecting the key terms from positive reviews and negative reviews, the research uses K-means clustering algorithm to cluster the customer reviews. In clustering analysis process, delete the review without the key terms and calculate the cosine similarity to understand correlation between all pairs of comments. A total 1,213 sets of positive reviews categorized into the three groups and 483 sets of negative reviews categorized into the four groups are calculated by R-Squared (RS) and root-mean-square standard deviation (RMSSTD).

According to the clustering analysis of the positive key terms, cluster 1 reviews mostly discuss about the customer's emotion, the overall of mobile phone appearance, and performance. In cluster 2, the reviews focuses on the battery which can be charged fast. The reviews also mentioned that the app, performance, appearance, camera, signal and connection of mobile phone. The reviews of cluster 3 focuses on the price of the product. It also discusses about the mobile phone performance, customer's emotion and behavior. The brief result of the positive key terms clustering are shown in Table 1.

Table 1. The summary result of the positive key terms clustering.

Cluster 1 (89 reviews)		**Cluster 2 (446 reviews)**		**Cluster 3 (678 reviews)**	
Category	Key terms	Category	Key terms	Category	Key terms
Emotion	love	Battery	battery, battery life, charge	Price	price, phone price, money, great price, cheap
Appearance	size, big	Software	app	Performance	fast, perform
		Performance	perform, fast		
		Appearance	button, big, size, slot	Emotion	happy, love, satisfy, love asus
Performance	perform, quality, fast	Camera	camera	Behavior	recommend, high recommend
		Signal and Connection	sim, call, dual sim, lte		

On the side of negative key terms, cluster 1 mainly discusses about dissatisfied the customer service of replacement or repairs. In cluster 2, the reviews focuses on the signal and connection of sim card or network. Its also mentioned the appearance and bad performance of mobile phone. As regards cluster 3, reviews complain to the battery (can not remove battery and battery drain fast) and the bloatware. Furthermore, its mentioned that some customers were not satisfied with the design of power button. Cluster 4 reviews focuses on the mobile phone screen and touch function and indicates the camera and bad performance such as mobile phone freeze or heat up. Signal and connection, customer's emotion and phone accessories are mentioned in cluster 4. The abbreviated result of the negative key terms clustering are summarized in Table 2.

Table 2. The summary result of the negative key terms clustering.

Cluster 1 (20 reviews)		**Cluster 2 (40 reviews)**		**Cluster 3 (139 reviews)**		**Cluster 4 (284 reviews)**	
Category	Key terms	Category	Key terms	Category	Key terms	Category	Key terms
Service	service customer-service customer	Signal and Connection	sim sim card lte network	Battery	battery battery-life charge power remove drain	Screen	screen touch
						Camera	camera
						Performance	freeze heat restart
Behavior	replace repair	Appearance	slot plastic	Software	app bloatware	Signal and Connection	bluetooth internet call lte miss
		Performance	stop defect hot stop-work	Appearance	button power-button	Emotion	disappoint
						Accessories	earphone case protector

2.5. Perceptual mapping

Collecting the customer reviews of competitors' products and extracting key terms to compare and analyze product positions is the mainly function of perceptual mapping. Three competitors' products are collected to compare including Sony Xperia M4 Aqua Dual, LG G3, and Samsung Galaxy Alpha. The price and camera are selected as two variables in the study. For draw the perceptual map, the average of highest and lowest price for each product is used in place of the real price because the purchased price can not be collected on Amazon.com. The related information including the product's average price and camera features are integrated in Table 3.

Table 3. The comparison of the case and competitors' products.

Product	**ASUS ZenFone 2**	**Sony Xperia M4 Aqua Dual**	**LG G3**	**Samsung Galaxy Alpha**
Total reviews	1696	107	461	241
Positive reviews	1213	76	364	197
Negative reviews	483	31	97	44
Time to market	May 2015	June 2015	May 2014	September 2014
Period of reviews	2015/5/18 to 2015/11/4	2015/7/17 to 2015/12/22	2014/7/10 to 2015/12/21	2015/2/27 to 2015/12/18
Avg. price (USD)	264	249.99	320	349.99
Rear camera	13 Mega-Pixel	13 Mega-Pixel	13 Mega-Pixel	12 Mega-Pixel
Front camera	5 Mega-Pixel	5 Mega-Pixel	2.1 Mega-Pixel	2.1 Mega-Pixel

The research uses NTF–IDF value of related key term to draw the perceptual map. Besides, the NTF–IDF values from negative reviews will be negative values. In this case, the research would draw the perceptual map by using the NTF–IDF value of the word "camera." The two dimensions perceptual map displays in the box-and-whisker plot is shown in Figure 1. The box plot is a standardized method of displaying the distribution of a dataset based on the five number summary including minimum, first quartile, median, third quartile, and maximum. Box plot also can be used to compare several different populations. In the box plot, the line in the box indicates the median and the top and bottom lines of the box indicate third and first quartiles. Therefore, 50% of the sample polutation fall inside the box. In addition, the lower and upper bars represent the lower 2.5% and the upper 97.5% of the distribution. The outliers are plotted as points in Figure 1. Due to the box plot of Sony is relatively tall and lower site than others, it represents that customers hold inconsistent opinions about the camera feature and reviews of Sony camera wouldn't better than the others. As regards the box plot of ASUS, more positive reviews of camera features than negative ones because it located approaching the positive region. ASUS has lots of outliers and negative outliers are more than positive ones. This might indicate that ASUS could pay more attention to these negative comments.

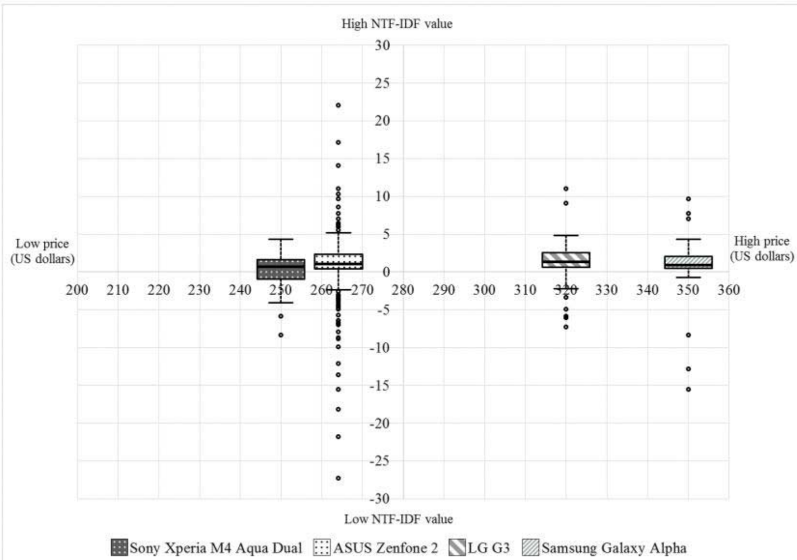

Figure 1. Perceptual map with the box plot (price vs. camera).

The proportion of the four products reviews related to key word "camera" is shown in Figure 2. To determine whether there is a significant relationship between the brand and the reviews with key word "camera" or not, the research uses chi-square test of independence. Chi-square test of independence could be used to examine two variables' association. The hypothesis test for H_0 is that there is not a significant association between the two variables, and H_1 is that there is a significant association between the two variables. The related mathematical formula is shown in Equation 1.

Using the number of reviews which mentioned the "camera" and the number of reviews which don't mentioned the "camera" to calculate the chi-square test statistic $\chi^2 = 23.5653$, with $df = 3$ and $\alpha = 0.05$. This chi-square distribution had threshold of 7.815. Since the value of test statistic (23.5653) was more than threshold value, we should reject H_0. Under the significance level of $\alpha = 0.05$, the study verifies products may have some association with the status of reviews.

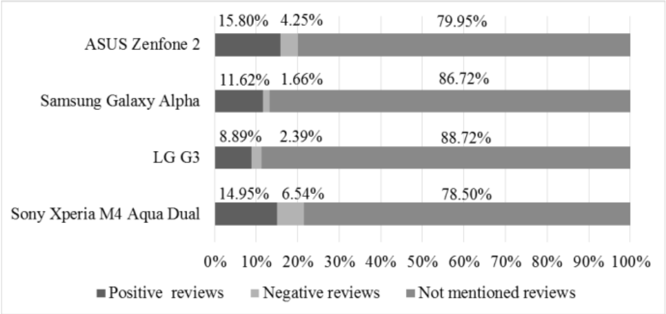

Figure 2. The proportion of reviews related to key word "camera."

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{(O_{ij}-E_{ij})^2}{E_{ij}} \qquad (1)$$

$$O_{ij} = n_{ij} \text{ and } E_{ij} = \frac{n_{i.} \times n_{.j}}{N}$$

The research uses Based on the proportions of reviews related to key word "camera" (Figure2), this study uses Z test to compare two population proportions and calculate the Z test statistic (Z_s). The mathematical formula is shown in Equation 2. The hypothesis test for H_0 is $p_1 - p_2 \geq 0$, and H_1 is $p_1 - p_2 < 0$.

$$Z_S = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}\hat{q}(\frac{1}{n_1}+\frac{1}{n_2})}} \sim \mathrm{N}(0,1) \qquad (2)$$

$$\hat{p} = \frac{n_1\hat{p}_1 + n_2\hat{p}_2}{n_1 + n_2} \quad \text{and} \quad \hat{q} = 1 - \hat{p}$$

$\hat{p}_1$ is the proportion in sample 1. n_1 is the size of sample 1.

Under the significance level of $\alpha = 0.05$, when $Z_s \leq -1.645$, there is enough evidence to reject H_0. The value of Z_s and the results of Z test are shown in Table 4. As the results of Z test, ASUS is significant larger than LG and Samsung based on the percentage of the positive reviews with key word "camera." Furthermore, Sony cellphone is significant larger than LG cellphone. On the other hand, ASUS is significant larger than LG and Samsung based on the percentage of the negative reviews with key word "camera." Sony is also significant greater than LG and Samsung cellphone.

Table 4. The results of Z test.

Product($\hat{p}_1$) / Product ($\hat{p}_2$)	ASUS ZenFone 2	Sony Xperia M4 Aqua Dual	LG G3	Samsung Galaxy Alpha
ASUS ZenFone 2	-	(P) -0.2337	(P) -3.7542*	(P) -1.6890*
		(N) 1.1257	(N) -1.8402*	(N) -1.9344*
Sony Xperia M4 Aqua Dual	(P) 0.2337	-	(P) -1.8794*	(P) -0.8638
	(N) -1.1257		(N) -2.2109*	(N) -2.4022*
LG G3	(P) 3.7542	(P) 1.8794	-	(P) 1.1513
	(N) 1.8402	(N) 2.2109		(N) -0.6319
Samsung Galaxy Alpha	(P) 1.6890	(P) 0.8638	(P) -1.1513	-
	(N) 1.9344	(N) 2.4022	(N) 0.6319	

Note: *: Significant (α = 0.05), reject H_0 ; (P): positive reviews; (N): nagetive reviews.

The research suggests that ASUS improves the design of cellphone camera, battery, screen, and connection technology. The decision makers and developers should reduce the bloatwares or let users remove the battery by themselves. The customer service can be examined and verified to make them feel satisfied. the system of mobile phone can be enhanced to keep it working stably and prevent the heat up. Since the reasonable price of ZenFone 2 has much praise from the customers, ASUS should keep using the strategy of parity price to create competitive advantage for the new generation product. Sony Xperia M4 Aqua Dual is a stronger competitor's product than others since there are no significant differences between their percentage of the positive reviews. The research suggests that ASUS should pay more attention on the trend of Sony. Furthermore, the average prices of LG G3 and Samsung Galaxy Alpha are higher than ASUS ZenFone 2, while their camera features are not as good as ZenFone 2's, ASUS can consider increasing the price of future products or improve other weaknesses first.

3. Conclusions and Future Research

The results of this study can be used as a reference for enterprises to efficiently understand customer experience and feeling from a lot of online reviews. Though the post-purchasing experiences of the consumers, the company finds the direction of product redesign to improve constantly. The methodology of this research discover the customer-preferred product functions and features to understnand the differnece between other competitors' products.

In the future, this research will implement the heterogeneous information network to develop a method which assists companies to forecast the customer needs. Using different types of objects and interactions to show the relationship between all the objects to represent an abstraction of the real world. The research hopes that the forecast from heterogeneous information network method will help companies to seek new potential customers.

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Variable Neighborhood Search for Transmission Network Expansion Planning Problem

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Abstract. This paper explores the metaheuristic Variable Neighborhood Search (VNS) to solve the static long-term power transmission network expansion planning problem that consists of finding the optimum expansion arrangement (construction of new circuits) for a horizon of defined planning. VNS is a simple and effective metaheuristic for combinatorial optimization that changes neighborhood within a local algorithm, and makes the choice of implementations that integrate intensification and/or diversification strategies during the search process. The formulation of the proposed method is presented, illustrating implementation details in the transmission network expansion planning problem using the transportation model. Results obtained in tests performed with a medium network available in literature are summarized.

Keywords. Variable neighborhood search, Network expansion planning, Metaheuristics

Introduction

The static long-term power transmission network expansion planning (TNEP) is an important stage of power system planning, and it is a large, complex mixed integer nonlinear programming that can be definided as: Given the network configuration for a certain year and the peak generation/demand for the next year (along with other data such as network operating limits, costs, and investment constraints), one wants to determine the expansion plan with the lowest cost. That is, where and what type of circuits should be built appropriately for the system to operate in a planning horizon for a specific increased demand.

The ideal mathematical modeling to indicate the appropriate operation would be the representation of the problem by mathematical relationships of the AC load flow, typically used in the analysis of the operation of the electric system. However, this modeling still cannot be used in an efficient way in transmission network planning, due to its non-convex and non-linear nature. Consequently, the mathematical modeling considered ideal in transmission system planning is the DC model, which take into account the two Laws of Kirchhoff, just for balance and active power flow. In this case, the resulting problem is a non-linear integer mixed programming problem with high

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complexity for large systems, presenting the phenomenon of combinatorial explosion of the number of alternatives in the search space, with the extra difficulty of presenting many local optima, which most of the time are poor quality.

A more simplified modeling is the so-called transportation model which just considers the First Law of Kirchhoff. In this case, the resulting problem is an integer linear programming problem. Despite being linear, it is still not possible to find the optimal solution for the transportation model when considering large and complex instances. In this paper we have used the transportation model but the proposed metaheuristic can be easily extended to the DC model.

Technical literature related to the TNEP problem proposes a lot of solution techniques. Those techniques can be separated into two groups: (i) exact methods of optimization, such as the Decomposition of Benders and Branch and Bound algorithms [1] and, (ii) approximate methods (heuristic and metaheuristic).

Heuristic techniques [2] are alternatives to solve mathematics optimization models. The term heuristic (a method of solving problems through practical techniques learned from past experiences; irregularly formed from the Greek word 'heuriskein', which means to discover, invent an idea), is used to describe all techniques that instead of using an approach of classical optimization, generates, step by step, a solution evaluating and selecting expansion options, with or without the help of the planner. These methods have the advantage of providing good quality solutions with small computational efforts, but also do not guarantee that meet the optimal solution of real systems and do not provide information on the quality of the obtained solution.

Already metaheuristic algorithms describe how to explore the space search without being tied to a specific problem(Simulated Annealing [3] (SA), Genetic Algorithms (GA) [4], Tabu Search (TS) [5], GRASP [6]). These algorithms coordinate simple heuristics with a local search in order to find better quality solutions than obtained using heuristics alone, that means, metaheuristics try to escape from local optima.

A varied bibliography about the theory and application of metaheuristics can be found in [7], [8], [9], [10], whereas in [11] a varied bibliography regarding the application of optimization techniques in the TNEP problem can be found.

In this work was considered a metaheuristic of the algorithms family called Variable Neighborhood Search (VNS) to solve the TNEP problem. The VNS metaheuristic was presented in the middle of the 90's, by Meladenovic and Hansen [12] and represents a significantly different proposal than other metaheuristics. The fundamental idea of the VNS algorithm is based on a basic principle: To explore the space of solutions by systematic changes of neighborhood structures during the search process. Thus, the transition through the search space of the problem is always accomplished with an improvement of the objective function and, therefore, the transition is not allowed for a solution of worse quality as occurs with most of the metaheuristics.

The VNS algorithm was used with success in the optimization of several problems of operational research but it is still insignificant in the optimization of problems related to the operation and the planning of electric power systems.

This paper is organized as follows: Initially the mathematical model for TNEP problem and the VNS metaheuristic are presented. After, the developed VNS algorithm to solve the TNEP problem is described. Later, obtained results are presented and commented. Finally, conclusions are drawn.

1. The Mathematical model of TNEP

The mathematical formulation of the TNEP for the transportation model has the following form [13]:

$$Min\ v = \sum_{i,j \in \Omega} c_{ij}.n_{ij} \quad (1)$$

$$Af + g = d \quad (2)$$

$$0 \leq g \leq \bar{g} \quad (3)$$

$$0 \leq n_{ij} \leq \bar{n}_{ij} \quad (4)$$

$$n_{ij} \geq 0 \text{ integer} \quad (5)$$

$$f_{ij}, \theta_j \text{ free} \quad (6)$$

The mathematical model (1-6) is a linear integer mixed programming problem where, c_{ij}, n_{ij}, n_{ij}^0 , f_{ij} and $\bar{f}_{ij}$, represent respectively the cost of a circuit or facility that can be added in the branch (i,j), the number of circuits added during the optimization process, the number of existing circuits in the base topology, the total power flow through the circuits, and the transmission capacity of a circuit through branch (i,j). The objective function (1) representing the investiment cost of a new transmission facility, and A is the transposed node-branch incidence matrix of the power system, g is a vector with elements g_k (power generation at bus k) with maximum values $\bar{g}_k$, $\bar{n}_{ij}$ is the maximum number of circuits that can be added to branch (i,j) and Ω represents the set of branches where it is possible to add circuits. Kirchhoff's Current Law is represented by (3), applied to each bus of the system. Inequations (4) represent capacity constraints for transmission lines, whereas the absolute value is necessary since power can flow in both directions. Other constraints represent operational limits of the generators, maximum limit for the addition of circuits per branch, and integrality demand of variables n_{ij}.

The model (1-6) can be solved by using traditional algorithms such as the branch-and-bound algorithm. This algorithm finds the optimum solution of the TNEP problem for the transportation model considering small and medium-complexity instances [1]. Nonetheless, for complex and multi-modal systems the branch-and-bound algorithm does not converge even with high processing times. Therefore, metaheuristics become suitable optimization tools for finding optimal and sub-optimal solutions for the TNEP problem considering complex power systems. Examples of instances for the TNEP problem where optimal solutions still remain unknown, even considering the transportation model in which the simplest model to be solved are found in [13].

2. VNS Algorithm

A metaheuristics is a search strategy through the search space of a complex problem. This search is performed by means of transitions in the search space from an initial point or a set of initial points. In this context, the main difference among the diverse metaheuristics techniques is the strategy used to carry out the transitions within the search space. VNS is a recent metaheuristics that systematically exploits the idea of neighborhood change to find local-optimal solutions and to leave those local optima. In that fundamental aspect, VNS is significantly different from other metaheuristics. Most metaheuristics accept the degradation of the current solution as a strategy to leave a local-optimal solution. The VNS algorithm does not accept this possibility.

The VNS algorithm changes the neighborhood as a way of leaving local-optimal solutions. During this process, the current solution is also the incumbent, which does not happen with other metaheuristics. Thus, it is possible to state that the VNS algorithm performs a set of transitions in the search space of a problem and at each step this transition is performed for the new incumbent. If the process finds a local optimum, then the VNS algorithm changes the neighborhood in order to leave from that local optimum, and to achieve the new incumbent. As a consequence of this strategy, if the VNS algorithm finds the global optimum the search stops at that point, eliminating any chance of leaving it. This behavior does not occur with other metaheuristics.

The strategy of the VNS algorithm is inspired by three important facts [14]:

Fact 1- A minimum with regard to one neighborhood structure is not necessary for another;

Fact 2- A global minimum is a local minimum with regard to all possible neighborhood structures;

Fact 3- For many problems, a local minimum with regard to one or several neighborhoods are relatively close to each other.

The latter is particularly important in the formulation of the VNS algorithm. This empirical fact implies that a local-optimal solution often provides important information regarding the global one, especially if the local-optimal solution presents excellent quality. It is also an empirical fact that local-optimal solutions are generally concentrated in specific regions of the search space. If local-optimal solutions were to be uniformly distributed in the search space, all metaheuristics would become inefficient. Consequently, if a local optimum is found in the same region where the global optimum is, then the VNS metaheuristic has better chances of finding this global optimum. On the other hand, if the global optimum pertains to another region then the only possibility to find it is to implement a diversification process. For this reason, equilibrium between intensification and diversification during the search process can be important in a metaheuristic.

There is another important aspect related to the quality of the local optimum that should be part of the implementation logic of a VNS algorithm. A local optimum with a better-quality objective function is not necessarily more suitable for trying to find the global optimum. Let $x_a$and $x_b$be two local-optimal solutions whit $f(x_a) < f(x_b)$ for the minimization problem. Considering the traditional analysis, it can be concluded that x_a is a local optimum with better quality than x_{ab}. If these solutions are to be used for initiating (or re-initiating) the search process, then it can be affirmed that the solution presenting internal characteristics closer to those of the global optimum is the most suitable for initiating (or re-initiating) the search, and, consequently, solution should not necessarily be chosen. Thus, for instance, considering the TNEP problem, the local-optimal solution with the largest number of n_{ij} elements equal to the optimal solution is the most appropriate for initiating (or re-initiating) the search. It is evident that in normal conditions, the optimal solution is unknown. However, there are some problems where the optimal solution is known and there are also various heuristic algorithms to find local-optimal solutions for this problem. In this way, the previous observation can be used to identify the heuristic algorithm that produces best-quality local-optimal solutions for initiating the search using the VNS algorithm. This type of behavior occurs in the TNEP problem where for some instances (power systems) optimal solutions are known and various constructive heuristic algorithms used to find excellent local-optimal solutions are available. Thus, the best constructive heuristic algorithm to be incorporated into the solution structure of a VNS algorithm can be identified.

Since the VNS algorithm can be implemented in various ways, a family of VNS algorithms can also be implemented. In [14] diverse types of VNS algorithms that can be implemented, are analyzed. In this work, only one of these algorithms is presented. Let N_k, $k = 1, \dots, k_{max}$, be a finite set of pre-selected neighborhood structures, and let be $N_k(x)$, a set of solutions or neighbors in the $k-th$ neighborhood of x. An optimal solution x_{opt} (or global minimum) is a solution where the minimum of (1-6) is achieved. A solution x' is a local minimum of (1-8) with regard to $N_k(x)$, if there is no solution $x'' \in N_k(x) \subseteq X$, such that $f(x'') < f(x')$. Thus, the idea is to define a set of neighborhood structures that can be used in a deterministic, random or both deterministic and random manner. These different forms of using the neighborhood structure lead to VNS algorithms with different performances.

There are various proposals of VNS algorithms that can be used independently or in an integrated manner forming more complex VNS structures. The simplest form of a VNS algorithm is the Variable Neighborhood Descent (VND). The VND algorithm based on the previously mentioned Fact 1, i.e., the local minimum for a given move, is not necessarily the local minimum for another type of move [14]. In this way, the local optimum x' in the neighborhood $N_1(x)$ is not necessarily equal to the local optimum x'' of x' for the neighborhood $N_2(x)$. The VND algorithm takes on the form shown in Figure 1.

Initialization: Select the set of neighborhood structures N_k, $k = 1, \dots, k_{max}$, that will be used in the descent; find an initial solution x;

Repeat the following sequence until no improvement is obtained:

(1) Set $k = 1$;

(2) Repeat the following steps until $= k_{max}$:

(a) Exploration: Find the best neighbor, x', of x ($x' \in N_k(x)$);

(b) Move or not. If the solution x' thus obtained is better than x, set $x = x'$ and $k = 1$; otherwise set $k = k + 1$.

Figure 1. VND algorithm.

This algorithm can be integrated into a more complex structure of the VNS algorithm.

The second type of VNS algorithm is called Reduced Variable Neighborhood Search (RVNS). This type of algorithm is inspired by two fundamental aspects during the search process related to intensification and diversification. On the one hand, Fact 3 states that in the region of a local optimum there are normally other local-optimal solutions that can be found from an initial local optimum and, consequently, an intensification strategy should be set up to try to find these local optima. On the other hand, leaving a valley in order to find a local optimum in a more distant region requires a strategy that considers a more radical change for characterizing the neighborhood - especially for problems with complex landscape.

It should be observed that the RVNS algorithm chooses neighbors more dynamically by selecting those from all neighborhood structures (diversification) and prioritizing the first neighborhood structure (intensification) during the initial stages of the search. Nevertheless, an important component of the RVNS structure is its capacity for finding new promising regions from a local optimum. The RVNS algorithm can also be used independently or be integrated into a more complex structure of the VNS algorithm.

More efficient VNS algorithms can be formulated by integrating those characteristics of the VND algorithm that allow local quality optima to be found, and those of the RVNS algorithm that allow new promising regions from a local optimum to be found. Thus, by merging those characteristics, two types of VNS algorithms that generally exhibit excellent performance can be formulated. These algorithms are called the Basic Variable Neighborhood Search (BVNS) and the General Variable Neighborhood Search (GVNS).

The BVNS algorithm combines a local search with systematic changes of neighborhood around the local optimum found [14]. The structure of the BVNS algorithm is presented in Figure 2.

Initialization: Select N_k, $k = 1, \dots, k_{max}$; find an initial solution x; choose a stopping condition;
Repeat the following sequence until the stopping condition is met:
(1) Set $k = 1$;
(2) Repeat the following steps until $= k_{max}$:
(a) Randomly generate a solution neighbor x', of x $(x' \in N_k(x))$;
(b) Local search: Apply a local search method with x' as an initial solution; denote with x'' the obtained local optimum;
(c) Move or not. If the solution x'' thus obtained is better than x, set $x = x''$ and $k = 1$; otherwise set $k = k + 1$.

Figure 2. BVNS algorithm.

The logical procedure adopted by the BVNS is very interesting. Firstly, k neighborhood structures should be chosen. The optimization process is initiated from a solution x and the corresponding neighborhood $N_1(x)$. Then, a neighbor x' of x in $N_1(x)$ is randomly selected. From x', a local search process to find the local optimum x'' is started. In this context, three cases may occur: (1) if x'' it means that x' already was the local optimum of the valley and, consequently, a change of neighborhood level should be performed ($N_2(x)$in this case); (2) if x'' is worse than x' then the a local optimum with less quality than the incumbent x was found and a change of neighborhood should also be carried out; and, (3) if x'' is better than x' it means that a better solution than the incumbent was found and, consequently, the incumbent should be updated, and the search should be re-initiated from the new incumbent while remaining in the neighborhood N_1. Whenever the local search finds a new incumbent, at any iteration of the process, the neighborhood $N_1(x)$ should be considered again. Also, whenever the local search finds an equal or worse quality solution than the incumbent, a change towards a more complex neighborhood should be performed. This strategy and the random choice of the incumbent x' neighbor avoid cycling and allow local optima which are distant from the current incumbent to be found.

The local search of the BVNS algorithm can be any heuristic strategy. Nonetheless, the local search can also use a strategy of the VNS algorithm. Therefore, the BVNS algorithm can be transformed into a more general algorithm called General Variable

Neighborhood Search (GVNS). The GVNS algorithm is obtained through the generalization of the BVNS algorithm by simply using a VND algorithm as a local search and using a RVNS algorithm to improve the initial solution required to begin the search. The GVNS algorithm is shown in Figure 3.

All observations made for the BVNS algorithm remain valid for the GVNS algorithm. As commented previously, the fundamental change corresponds to the improvement stage of the initial solution using an RVNS algorithm and a VND algorithm for the local search stage. There are other more complex algorithms or structures based on the logic of the VNS algorithm that are out of the scope of this work. Those algorithms can be found in [14] and [15].

3. VNS for TNEP Problem

In this section, the different stages of the VNS applied to the TNEP problem will be presented.

The GVNS described in Figure 3 will be used considering the following steps that will be explained in detail in the sequence:

Step 1- Initial solution: Use a heuristic algorithm to determine an initial solution;

Step 2 - Definition of neighborhoods: Characterize each neighborhood and determine its elements;

Step 3- Improvement: Improve the initial solution by using a RVNS algorithm;

Step 4- Local search: Apply some local search to determine the best configuration for each neighborhood of the current solution.

3.1 Step 1: Initial Solution

To generate an initial solution, a constructive heuristic algorithm (CHA) will be used, i.e., an iterative process of choices or decisions taken step by step that determines a good-quality solution of a complex problem. As for the TNEP problem, at each step a circuit is chosen to be added to the system, whereas the choice is given by a sensitivity indicator specified by the CHA. The iterative process is finished when a feasible solution - and generally of good quality - is found.

Although the CHA are robust and present fast convergence, when dealing with large and complex problems they only find good-quality local solutions that could be very different from the global optimum. The following subsection will introduce a CHA using the Transportation Model.

Garver's Heuristic Algorithm (GHA)

Garver's proposal [2] consists in solving the system (1-6) by relaxing the integrality of integer variables n_{ij}, and finding the continuous optimal solution for the current configuration $n_{ij}^c = n_{ij}^0 + n_{ij}^\alpha$ where n_{ij}^α are the circuits added during the iterative process of the CHA, is the maximum number of circuits that can still be added to branch (i, j), as in (7-13) model.

$$Min\ v = \sum_{i,j \in \Omega} c_{ij}.n_{ij} \tag{7}$$

$$Sf + g = d \tag{8}$$

$$|f_{ij}| \leq (n_{ij}^{C} + n_{ij}).\bar{f}_{ij} \quad (9)$$
$$0 \leq g \leq \bar{g} \quad (10)$$
$$0 \leq n_{ij} \leq \bar{n}_{ij} \quad (11)$$
$$n_{ij} \geq 0 \quad (12)$$
$$f_{ij}, \theta_j \text{ free} \quad (13)$$

Therefore, knowing n_{ij} from (7-13) by using an LP algorithm, it is possible to find the power flow through all the circuits of the current topology (n_{ij}^{c}) and through the circuits (generally non integer) added by (n_{ij}). Consequently, that branch where $n_{ij} \neq 0$ and presents the largest power flow represents the most attractive branch according to this proposal. A repetitive process of this strategy, adding a circuit to the most attractive branch at each step, makes up the GHA. The process ends when the solution obtained by the LP corresponding to the current configuration presents a solution with all $n_{ij} = 0$, which means that it is no longer necessary to perform more additions and that the set of performed additions represents the solution proposal by Garver's algorithm [2], that can be summarized by the following steps:

Step 1- Take on a base configuration as the current configuration.

Step 2- Solve the LP corresponding to the system ((7-13)) for the current configuration. If all $n_{ij} = 0$ then stop, since a good, feasible configuration was found. Otherwise, go to Step 3.

Step 3- Compute the power flows through all the new circuits added by the LP, ($n_{ij} \neq 0$), by using relation $f_{ij}^{v} = n_{ij}.\bar{f}_{ij}$. Identify the new branch (i, j) with the largest value of f_{ij}^{v} and update the current configuration by adding a circuit to that branch. Go back to Step 2.

In terms of mathematical optimization, the GHA is a constructive heuristic algorithm that, in practice, finds good-quality solutions. Finding the global-optimal solution is not guaranteed.

3.2 Step 2: Definition of Neighborhoods

Given a solution x, the following structures of neighborhood within the solution space can be defined as:

$$N_k(x) = \{x' \in S : d(x, x') = k, k = 1, \ldots, k_{max}\} \quad (14)$$

where $d(x, x') = k$ is the quantity of branches with a different number of added circuits in the solutions x and x'. Parameter $k = 6$ was adopted. As an example, consider the configuration x from Figure 3.

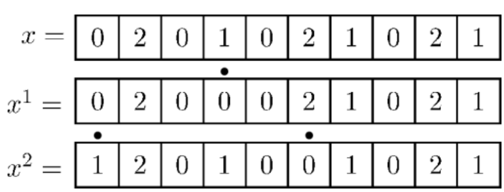

Figure 3. Neighborhood characterization.

Configuration x^1 is a neighbor of x in $N_1(x)$, and x^2 is a neighbor of x in $N_2(x)$. Neighbor x^1 as obtained from x by removing a circuit from branch 4, whereas the neighbor x^2 was obtained from x by adding one circuit to branch 1 and removing two circuits from branch 6. In this way, the neighbors in the other neighborhoods can be obtained.

3.3 Step 3: Improvement of the initial solution

Considering $k_{max} = 6$ and the same defined neighborhoods, with an initial solution already obtained, a local improvement search using a RVNS as described in Figure 2 is applied. The stop criterion corresponds to the maximum number of solved LPs. Note that this step only accepts movements that lead to feasible solutions.

3.4 Step 4: Local Search

The local search, in each neighborhood, was performed using model (10-16). Circuits in $N_1(x)$ were decreasingly ordered by costs, whereas those circuits that, after solving the corresponding LPs, do not produce load shedding in the system were removed. As for the remaining neighborhoods, the cost variations due to changes (cost difference between entering and leaving lines) were calculated and only the line changes that exhibited negative variation were simulated. If the simulation points out a feasible configuration, then it is a candidate to be used by updating the current configuration. If the configuration is unfeasible, then the simulation is cancelled. It is important to clarify that the movement will be only carried out if the new configuration is better than the incumbent.

4. Results

The proposed algorithm was implemented using the FORTRAN and MINOS 5.4 programming language, as a LP resolution sub-routine for the Brazilian Southern power system whose base topology. This system presents 46 buses, 79 circuits and a power demand of 6880 MW. Full data can be found in [16, 17]. The execution of planning with (R) or without (WR) generation re-programming is possible.

The BVNS algorithm achieves the global optimum of the R planning presented in [1], with $v = 53{,}334{,}000$, solving 19,623 LPs and using k_{max}= 4 neighborhood structures.

As for the WR planning, considering [1], the global-optimal solution requires an investment of US 127,272,000, solving 940,135 LPs and k_{max}= 6.

In order to reduce the size of the considered neighborhoods, only those added circuits operating below 70% of their capacity were considered to be candidate circuits for removal. As for the candidate circuits for addition to the system: for each neighborhood, the candidate branches were removed and the LP solved (7-13), then those branches with $n_{ij} \neq 0$, specified in the LP solution, were considered candidates for addition. With these considerations, the number of solved LPs decreases considerably in both analyzed cases: 2.496LPs and 155.920, respectively, to achieve the global optimum, and therefore more efficient than the methods shown in [4] and [5].

5. Conclusion

The mathematical modeling most suitable to represent the proper operation of TNEP would be through mathematical relationships AC load flow typically used in analysis of the electrical system operation. However this modeling also can not be used efficiently in the planning of transmission systems. In this work was considered the DC model whose mathematical formulation is nonlinear and mixed integer.

The TNEP is a multimodal problem of high complexity for medium and large systems and can not be solved by exact algorithms in reasonable computational times. It was presented a new proposal for a solution that uses a metaheuristic based on variable neighborhood search that systematically exploits the idea of neighborhood change to find local-optimal solutions and to leave those local optima. It was observed that the definition of neighborhood structures plays an important role to the convergence of the VNS algorithm applied to TNEP.

The algorithm has more chance of finding better solutions than mathematical optimization thecniques, and searches local optimal solution faster [17, 18].

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A Method for Automated Gait Pattern Classification

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Abstract. This work presents the development of a data mining application for gait pattern classification. The objective is to understand the differences and similarities among patterns of walking from healthy and unhealthy subjects groups. The data repository contains the spatial parameters of centers of pressure (CoP) trajectories during gait. The trajectory of each CoP is extracted from the contact points of the feet with the ground form each footprint. The data was collected with a GaitRite® Pressure Sensor Mat. The proposed method includes the standardization of data and creation of an organized repository (data warehouse) from previously collected data. Also, it includes the development of a process mining example to analytical comparison between these two different groups. A graphical analysis based on decision tree provides the interpretation of the pattern of 'signature' footprints. This study is the starting point to classifying different pathologies and assisting the rehabilitation treatments.

Keywords. Gait analysis, Pattern Analysis, Data mining, Pattern Classification, Signature Footprints

Introduction

The application of engineering in the medical field has been increasing over the years. In the gait analysis, the monitoring technologies based on biometric signals has provided improvements aiming to help the rehabilitation or assist on the early detecting of diseases [1 – 3]. Tools like cameras, force plates, footbridges and devices embedded in sidewalks are some examples of more recent allies of gait analysis study [4,5]. The data used in this work are provided by a pressure sensor mat. This mat creates a map containing the pressure variations of foot contact points during the walking [6].

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Due to the considerable amount of data achieved by this study, it demands too much time and resources to analyze it. To optimize the data analysis, we can use a method called Data Mining [7]. In Data Mining, the classification strategy (Decision Tree), is a supervised machine learning process. It find out a response variable (dependent variable) from predictor variables (independent variables) as in [8].

The group analyzed in the study consists of 22 healthy people (without any known pathology) and 7 people who has done surgery on their hips (4 Total Hip arthroplasty, 2 Endoprosthesis hip, 1 Dynamic "hip screw")[2]. These cases are common surgeries in orthopedic clinical, mainly in older patients [9].

It is estimated that in year 2060 the number of elderly will be more than 73,5 million in Brazil [10], in this way, there will be an increase of this type of analysis justifying a study in this field.

1. Proposed Method

For the development of this study it was necessary 3 steps, which are Organization of data, Calculation of Parameters and Data Mining. They will be better explained in the following subchapters.

1.1. Organization of data

The used data in this study are provided by Pressure Sensor Mat (from GaitRite®), which has been used since 2001 in several studies due its reliability [11-14]. The system consists of an electronic walkway where there are 18.432 pressure sensors embedded in an active area of 4,3 meters (length) x 0,6 meters (width).

The GaitRite calculates the trajectory of the pressure center generated by the people gait according to Figure 1 and 2.

The GaitRite system creates an exported file with CoP coordinate points, and it can be exported directly to Excel format, as presented in Figure 3.

This file contains five parameters about the CoP information. First column is the 'Obj.' representing a sequential number related to each footprint; i.e. for example, if it exits *n* footprints, the number changes from *1* to *n* in order to identify each one. The 'Time' is the parameter to save the 'contact time', the 'L/R' identifies the right foot = 1 and left foot = 0. The CoP's center coordinates is stored in respective (X, Y) columns. A specific file can be obtained for each exam.

The patients who have done exams using the pressure sensor mat were 22 healthy people (without any known pathology) and 7 people who have faced some surgery as shown in Table 1.

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[2] Data provided from Centre on Memory and Mobility Michel Rodange - Zitha Luxembourg and Luxembourg Institute of Science and Technology (LIST).

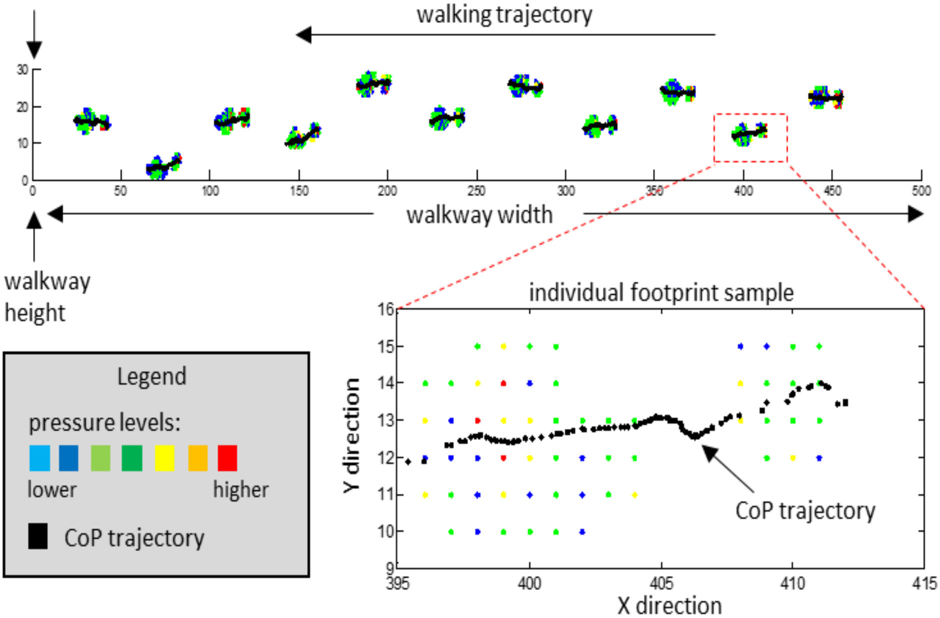
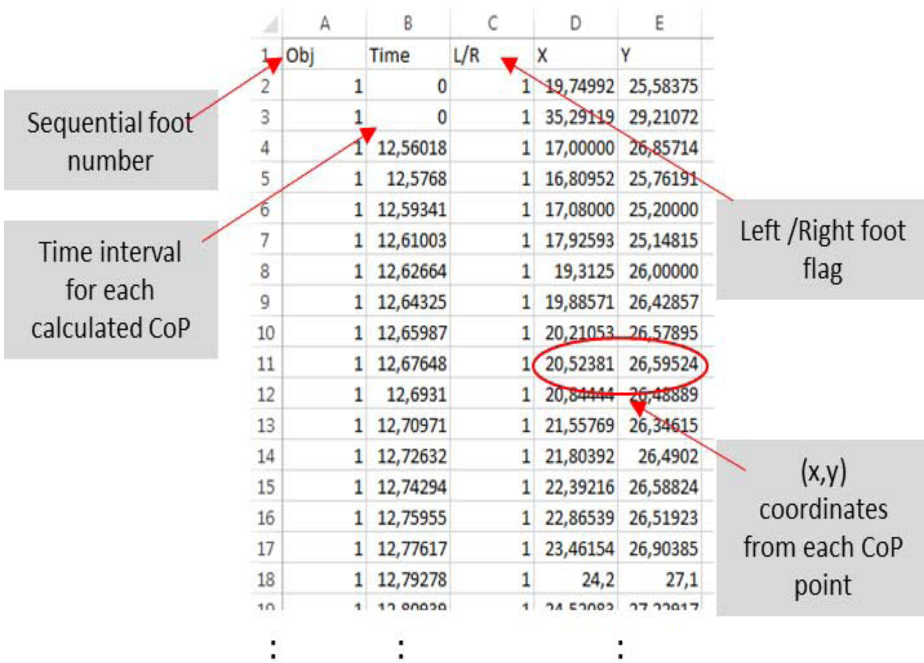


Figure 1. Footprints walking with respective pressure levels collected during walking and a CoP (center of pressure) trajectory of a sampled footprint.



	A	B	C	D	E
1	Obj	Time	L/R	X	Y
2	1	0	1	19,74992	25,58375
3	1	0	1	35,29119	29,21072
4	1	12,56018	1	17,00000	26,85714
5	1	12,5768	1	16,80952	25,76191
6	1	12,59341	1	17,08000	25,20000
7	1	12,61003	1	17,92593	25,14815
8	1	12,62664	1	19,3125	26,00000
9	1	12,64325	1	19,88571	26,42857
10	1	12,65987	1	20,21053	26,57895
11	1	12,67648	1	20,52381	26,59524
12	1	12,6931	1	20,84444	26,48889
13	1	12,70971	1	21,55769	26,34615
14	1	12,72632	1	21,80392	26,4902
15	1	12,74294	1	22,39216	26,58824
16	1	12,75955	1	22,86539	26,51923
17	1	12,77617	1	23,46154	26,90385
18	1	12,79278	1	24,2	27,1

Figure 2. Excel file imported from GaitRite®.

Table 1. Unhealthy Patients Characteristics.

Patient Id#	Gender	Age (Years)	Weight (kg)	Height (cm)	Surgery
30	Female	82	67	158	*Total Hip arthroplasty, Left*
31	Female	84	61	155	*Endoprosthesis hip, Right*
32	Female	69	66	166	*Total Hip arthroplasty, Right*
33	Female	84	69	163	*Endoprosthesis hip, Right*
34	Female	86	69	160	*Total Hip arthroplasty, Right*
35	Female	75	57	158	*Dynamic "hip screw", Left*
36	Female	83	86	168	*Total Hip arthroplasty, Right*

Those patients have been submitted to different examining protocols such as:

Table 2. Examining Protocols, as in [18].

Protocols	Type of Exercise
1	Self Selected Speed Walking (the normal way of walking)
2	Slow Walking
3	Fast Walking
4	Cognitive dual task walking (normal walking and counting backwards in steps of 2, starting at number 50 or 30 depending on the patient's condition);
5	Motor dual task walking (normal walking while carrying a glass of water filled by 2/3).

Each exam is based on the defined protocols (as in table 2) and it generates two files, one is when the individual is going (*walking up*) and another when patient is coming back (*walking down*). Thus, we have ten files for each one, where there is a big amount of data considering in this case with almost thirty people and five protocols. For the sake of data organization, all individual files were organized into a single file. In order to group these data, it was necessary define new attributes such as:

- Patient: it is a sequential number which corresponds to the identification of each individual;
- Protocol: that it corresponds to a specific protocol from performed exam;
- Way: it corresponds to a direction (coded as '1' to walking up and '2' to walking down), and
- Healthy: it shows the status of patient/individual condition as healthy or unhealthy.

Figure 3 shows this new arrangement and detailed explanations is provided in next section.

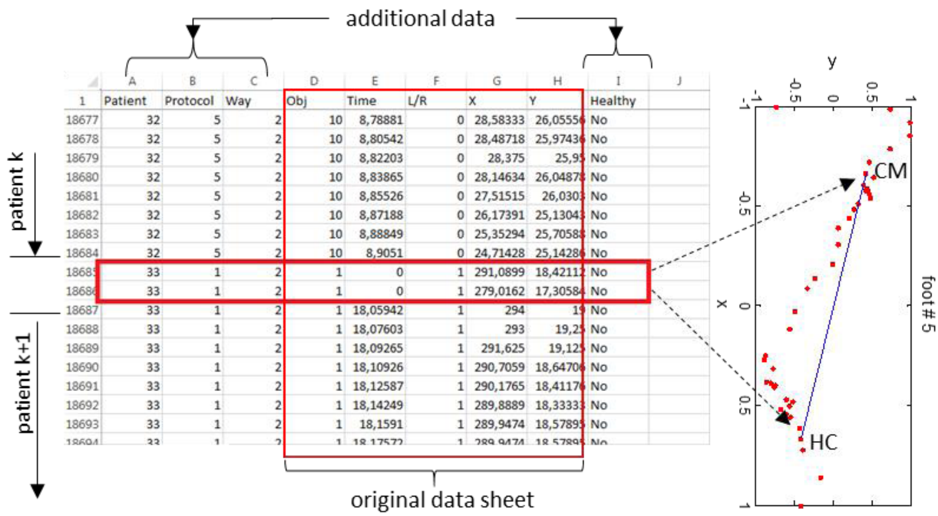


Figure 3. File containing all patient's exams and the necessary additional data to further datamining process.

1.2. Calculation of Parameters

For each 'object' (i.e. footprint) there are two points when the time is set up to 0 (zero), according to Figure 3. These points are both the center point of heel (HC) and center point of metatarsus (CM), which are shown by C1 and C2, accordingly, in the next figure 4. The figure 4.a presents the most outer sensors (numbered in figure as 1 to 6, as [6]) whose positions are the foot region limits. Thus, these points are used to calculate the range among the steps, in the other words, the distance from the center of heel (HC) to the next foot (HC_HC) and from the center of metatarsus (CM) to previous foot HC (CM_HC). The Figure 4(b) shows these distances.

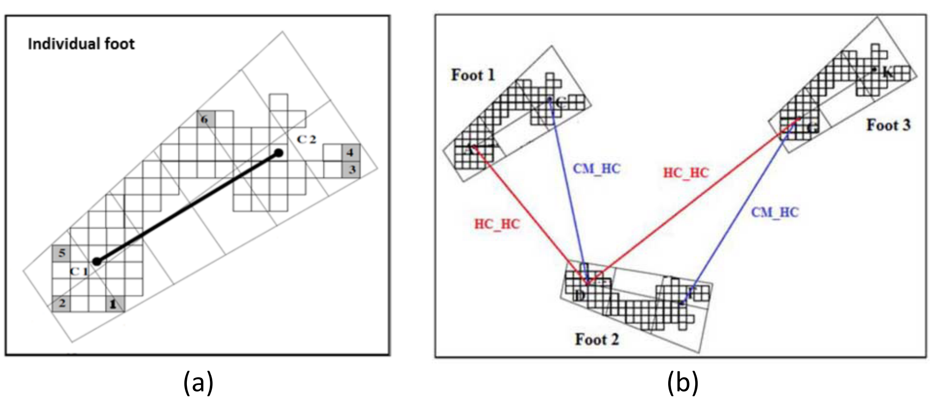


Figure 4. Measurement control points adapted from [6]. a) Center of heel and center of metatarsus, b) Distance between HC_HC and CM_HC.

The calculation of these distances are shown by the following equations:

$$\text{HC\_HC}=\sqrt{(XHC_{k+1}-XHC_{k})^{2}+(YHC_{k+1}-YHC_{k})^{2}} \tag{1}$$

$$\text{CM\_HC}=\sqrt{(XHC_{k+1}-XCM_{k})^{2}+(YHC_{k+1}-YCM_{k})^{2}} \tag{2}$$

In the equations X is the coordinate x and Y is the coordinate y of the corresponding point; HC is the center of heel and CM is the center of metatarsus; and the subscribed values are the foot index. After these values calculated, then a new file is created with a few changes in Excel file as column highlighted in Figure 5.

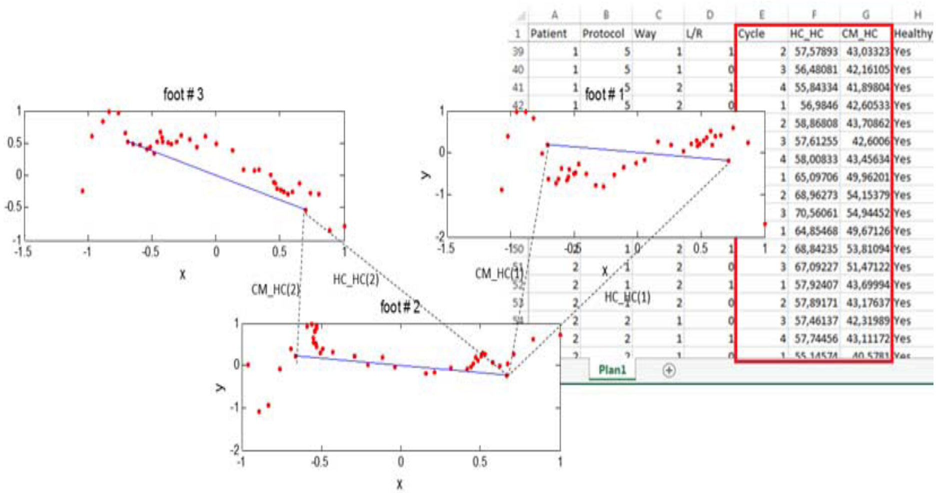


Figure 5. File containing the distance information.

In this new file we have ‘Cycle’ instead ‘Object’ because we need to link the right and left foot, and then we can see the variability of the distances HC_HC and CM_HC instead of the only individual ‘Coordinates’ (x,y). Is this way, the new file is prepared to datamining procedure.

1.3. Data Mining Procedure

Data Mining is the name of the process of knowledge discovery and relevant standards from a large amount of data [15]. Inductive strategy was adopted for discovering patterns and 'Decision Tree' to represent, because this method has as strategy the segmenting of complex problem to simple problems [16]. The software used is RapidMiner, one of the worldwide leading open-source software for data mining [17]. We can see the interface and the process of data mining developed in the Figure 6.

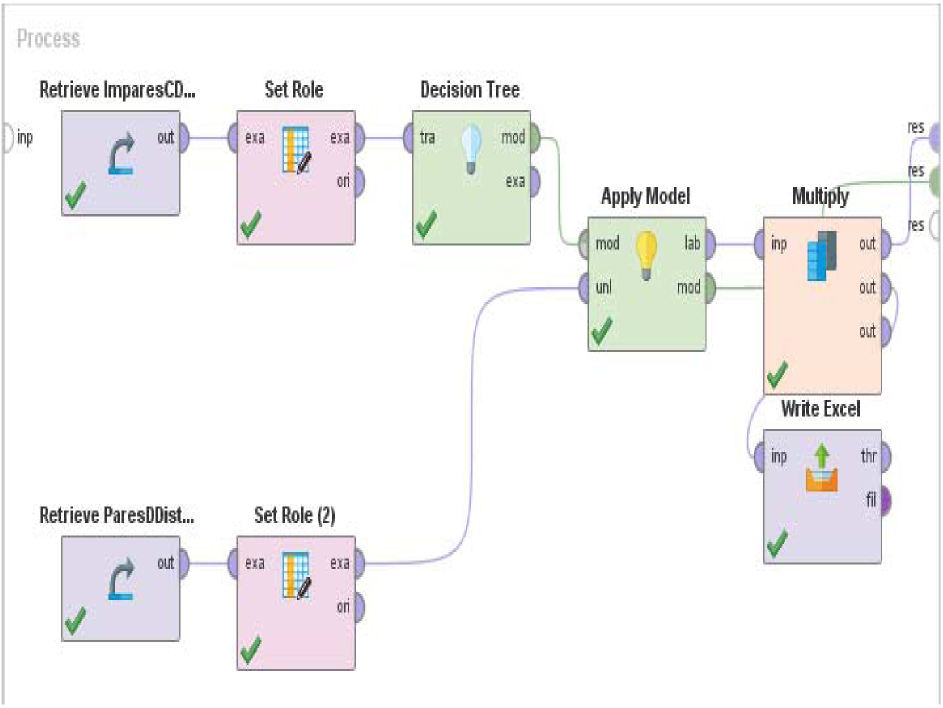


Figure 6. RapidMiner Studio Process.

In the process presented in figure 6 there are two ‘Retrieve’ activity. This is an operator with reading function of an object from the data repository. There are also two ‘Set Role’. This operator is used to change the role for each of the attributes. For our proposal, we have two roles. A first operator ‘Set Role’ is to assign the role identifier to the attribute "patient" just to its own identification as well as the “healthy” attribute is assigned as a label for it. The second ‘Set Role’ is related to testing data and it carries the attribute "Patient" only. The idea of the decision tree is to create the classification model whose function is to predict the classification of a value. The ‘Apply Model’ is the responsible for the model (decision tree) and it can be applied to another set of values for prediction. The ‘Multiply’ just multiplies the response of ‘Apply Model’ to one of the responses being the output and the another one will pass through ‘Write Excel’ in order to export this file.

2. Application of Method and Results

The process of Data Mining is based on a control group containing the distances acquired from the exams, 11 healthy patients and 3 patients who have done surgeries, to create the following Decision Tree. The purpose of this Decision Tree is to define a standard for determining automatically an opinion about the situation of the patient, in other words, if the patient is healthy or not.

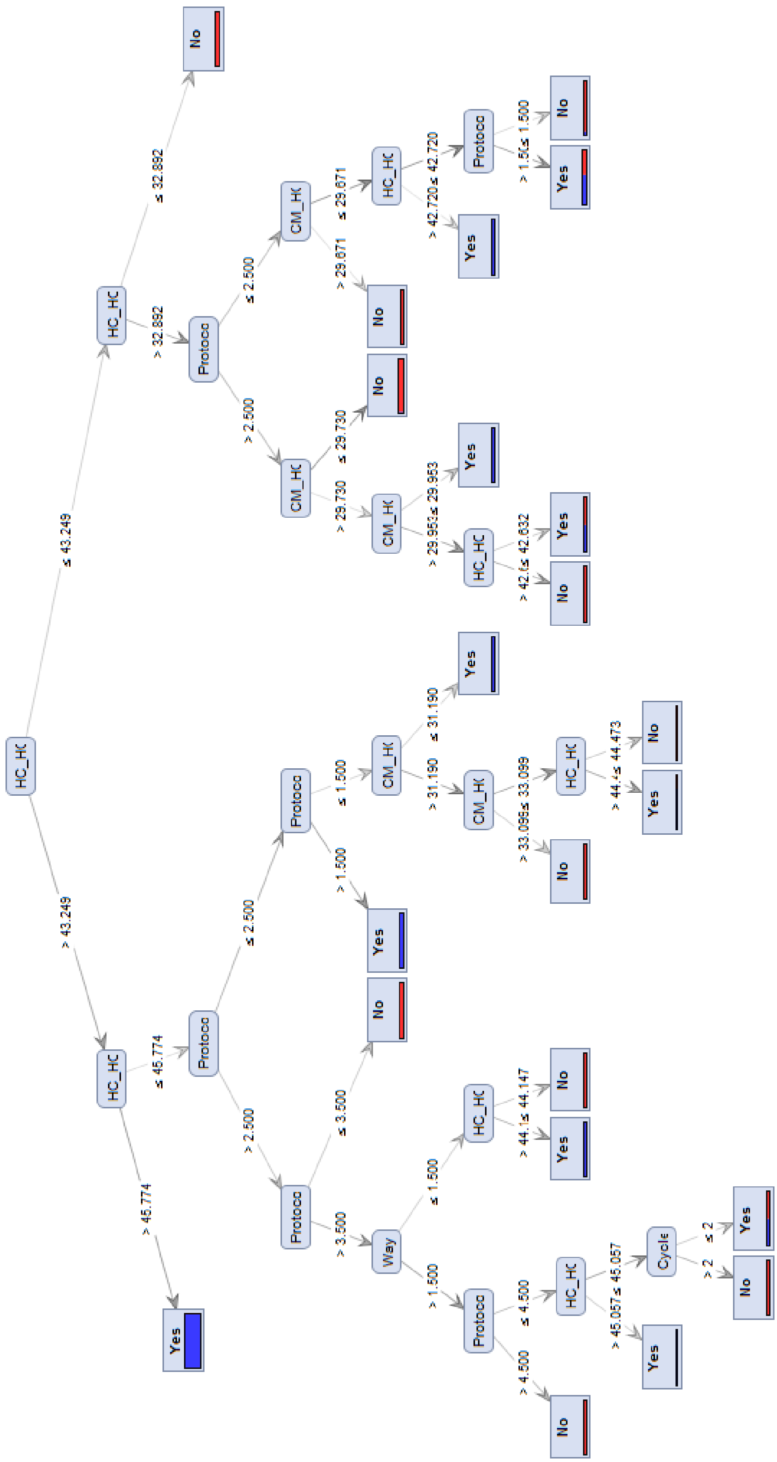


Figure 7. Decision Tree generated from proposed study case.

The next step of Data Mining is the model application, in this case, the Decision Tree. It will be applied to a test group, where there are 11 healthy people and 4 people who have done some surgery. This database, as opposed to the one used the create the Decision Tree, does not contain information about the patient healthy condition because the purpose is to generate an opinion for these patients. On this way a file was created where using the mining process we can determinate if the people are healthy or not. This file has 790 instances, in other words, lines containing information about the distances HC_HC and CM_HC, acquired from exams performed and calculation (Equation 1 and 2). In this study the process achieved an assertiveness of 95,19% (752 instances).

3. Conclusion

The study described on this project was developed using prominent data acquired from a sensor pressure mat. The main purpose was the proposal of a classification method as the health of the people examined. For the development of this proposal was used Data Mining Algorithm, Decision Tree and the open-source data mining software RapidMiner.

The results brought by this study were a Decision Tree definition and its respective worksheet, where the data mining determined the condition of each patient in the testing group.

The result acquired in this study case it was around 95% of assertiveness. Moreover, the unbalance between the number of cases with and without surgery, and the limited amount of data might have contributed to this optimistic result. New tests will be performed to verify the repeatability.

This method in the future can contribute to give the follow-up examinations in patients who has done surgery on their hips. As a future step the purpose is to obtain a better justification about the reasons of this result.

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Stochastic Analysis of the Kinematic Performance of a Planar 5R Symmetrical Parallel Mechanism

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Abstract. This paper aims at studying the kinematic model of the 5R symmetrical parallel mechanism considering the uncertainties in the lengths of links and the clearances in the active joints. The complete kinematic model of the 5R parallel mechanism is formulated in the presence of the uncertain parameters that are model as random variables. The stochastic analysis, based on the Monte Carlo Method, permits to evaluate numerically the performance of the mechanism when the uncertain parameters are considered. Thus, the kinematic model for several poses within the workspace is evaluated. Moreover, the variability in the workspace produced by the uncertain parameters is also analyzed.

Keywords. Kinematics, Parallel Mechanism, Monte Carlo Method, Uncertainties

Introduction

Parallel mechanisms have active and passive joints. Active joints are attached to actuators that provide mechanical power for the motion. Passive joints are under-actuated. In most cases, the joints are subject to clearances that deteriorate the overall performance of the mechanism. Additionally, manufacturing and assembling tolerances introduces small variations in the geometry of the joints that also produce positioning error affecting the performance of the mechanism. In agreement with this is necessary to quantify the effect of these uncertainties in order to analyze how these uncertainties affects the performance of parallel mechanism [1].

Several works have studied this issue in robotic manipulators considering different approaches. The probabilistic theory has been previously used in order to study the effects of uncertain parameters on the performance of robot manipulators. By using this approach, the uncertainties are modeled as random variables or random fields. Consequently, the reliability associated with the tolerances of geometrical and dynamical parameters of the manipulator are studied [2,3]. Moreover, Polynomial Chaos Theory was applied to study the effect of uncertain inertia and payload on SCARA robot dynamics [5]. Nevertheless, as an alternative approach to analyze the uncertain parameters of robotic manipulators, the fuzzy theory has been applied to analyze the dynamic behavior of robotic manipulators [6].

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This paper aims at analyze the kinematics of the 5R parallel mechanism subjected to uncertain length of the links and clearances of the active joints. In accordance with that, the forward/inverse kinematic model and the workspace were formulated as function of the aforementioned uncertain parameters. The uncertain parameters are modeled as random variables and they are introduced in the kinematic model of the mechanism. The Monte Carlo Simulation is the stochastic solver used in order to compute the numerical response of the kinematic model with the uncertain parameters. Finally, the numerical results are analyzed.

1. Kinematic Model

The 5R planar parallel mechanism has two active or actuated joints, three passive of free joints and four links. The geometry of the 5R symmetrical parallel mechanism is defined according to Fig. 1. The active joints are located at A_i and they are denoted as θ_i (for i = 1,2). The passive joints are located at the end of each link of the active joints Bi. The end effector of the mechanism is located at P that is defined by x and y Cartesian coordinates. Additionally, the fixed reference frame O is defined in the middle of A_1A_2, therefore the symmetry of the mechanism is defined by $OA_1 = OA_2$, $A_1B_1 = A_2B_2$ and $B_1P = B_2P$. Consequently, the geometry of the 5R symmetrical mechanism can be defined by $OA_i = \bar{r}_3\ (r_3)$, $A_iB_i = \bar{r}_1(r_1)$ and $B_iP = \bar{r}_2(r_2)$.

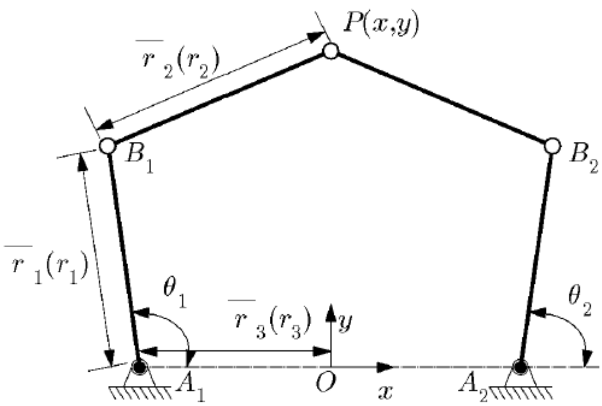


Figure 1. The 5R symmetrical parallel mechanism.

1.1. Inverse Kinematics

The inverse kinematic model defines the active joints θ_i as function of the position of end effector P. The position, P, of the end effector with respect of the fixed reference frame O is defined by the Cartesian vector $\mathbf{p} = (x, y)^T$. Additionally, the position of the points B_i (for i = 1,2) with respect to the fixed frame O is defined by the vector $\mathbf{b_1} = (r_1\cos(\theta_1) - r_3, r_1\sin(\theta_1))^T$ and $\mathbf{b_2} = (r_1\cos(\theta_2) + r_3, r_1\sin(\theta_2))^T$, respectively. The inverse kinematics is solved with the aids of the constraint equation $|\mathbf{b}_i\mathbf{p}| = r_2$, therefore:

$$(x - r_1\cos(\theta_1) - r_3)^2 + (y - r_1\sin(\theta_1))^2 = r_2^2 \tag{1}$$

$$(x - r_1\cos(\theta_2) + r_3)^2 + (y - r_1\sin(\theta_2))^2 = r_2^2 \tag{2}$$

by solving Eqs. (1) and (2) when **p** is known, θ_i can be determined:

$$\theta_i = \arctan(z_i) \tag{3}$$

where

$$z_i = \frac{-b_i + \sigma_i\sqrt{b_i^2 - 4a_i c_i}}{2a_i} \tag{4}$$

with

$\sigma_i = \pm 1$
$a_1 = r_1^2 + y^2 + (x + r_3)^2 - r_2^2 + 2(x + r_3)r_1$
$b_1 = -4yr_1$
$c_1 = r_1^2 + y^2 + (x + r_3)^2 - r_2^2 - 2\,(x + r_3)r_1$
$a_2 = r_1^2 + y^2 + (x - r_3)^2 - r_2^2 + 2\,(x - r_3)r_1$
$b_2 = b_1 = -4yr_1$
$c_2 = r_1^2 + y^2 + (x - r_3)^2 - r_2^2 + 2\,(x - r_3)r_1$

As seen in Eq. (4), the inverse kinematic has four different solutions that depend on the signal adopted by σ_i. The solution adopted in this paper considers $\sigma_1 = 1$ and $\sigma_2 = -1$. Based on Eqs. (3) and (4), the inverse kinematic can be expressed by the follow expression:

$$(\theta_1, \theta_2)^T = f(x, y, r_1, r_2, r_3) \tag{5}$$

1.2. Forward Kinematics

The forward kinematics model sets the position of end effector P as function of the active joints θ_i. It is obtained from Eqs. (1) and (2):

$$x^2 + y^2 - 2(r_1\cos(\theta_1) - r_3)x - 2r_1\sin(\theta_1)\,y - 2r_1r_3\cos(\theta_1) + r_3^2 + r_1^2 - r_2^2 \tag{6}$$

$$x^2 + y^2 - 2(r_1\cos(\theta_2) + r_3)x - 2r_1\sin(\theta_2)\,y + 2r_1r_3\cos(\theta_2) + r_3^2 + r_1^2 - r_2^2 \tag{7}$$

It is obtained from Eqs. (6) and (7):

$$x = ey + f \tag{8}$$

with $e = \frac{r_1(\cos(\theta_1) - \sin(\theta_1))}{2r_3 + r_1\cos(\theta 2) - r_1\cos(\theta 1)}$ and $f = \frac{r_1 r_3(\cos(\theta_1) + \cos(\theta_2))}{2r_3 + r_1\cos(\theta_2) - r_1\cos(\theta_1)}$. By substituting Eq.(8) to Eq. (6), it is obtained:

$$dy^2 + gy + h = 0 \tag{9}$$

with

$d = 1 + e^2$
$g = 2(ef - er_1 \cos(\theta_1) + er_3 - r_1 \sin(\theta_1))$
$h = f^2 - 2f(r_1 cos(\theta_1) - r_3) - 2r_1 r_3 cos(\theta_1) + r_3^2 + r_1^2 - r_2^2$

Considering Eq. 9,y can be obtained:

$$y = \frac{-g+\sigma\sqrt{g^2-4dh}}{2d} \quad (10)$$

From Eq. (10) is observed that the forward kinematic has two solutions corresponding to σ=1 or $\sigma = -1$. Based on Eqs. (8) and (10), the forward kinematic formulation can be summarized by the fallow expression:

$$(x, y)^T = f^{-1}(\theta_1, \theta_2, r_1, r_2, r_3) \quad (11)$$

1.3. Workspace of the Mechanism

The region of the workspace that the end effector can reach when the active joints θ_i variate from 0 to 2π is defined as the theoretical workspace, in this definition the collision between the links and the singularities are not considered. The theoretical workspace is enveloped by two following circles for the first leg:

$$C_{1o}: (x + r_3)^2 + y^2 = (r_1 + r_2)^2 \quad (12)$$

$$C_{1i}: (x + r_3)^2 + y^2 = (r_1 - r_2)^2 \quad (13)$$

For the second leg, the workspace is enveloped by circles:

$$C_{2o}: (x + r_3)^2 + y^2 = (r_1 + r_2)^2 \quad (14)$$

$$C_{2i}: (x + r_3)^2 + y^2 = (r_1 - r_2)^2 \quad (15)$$

The theoretical workspace is defined by the intersection of circles of Eqs. (12), (13), (14) and (15). The usable workspace is specified as the maximum continuous workspace that contains no singular loci, and also it is bounded outside by the singular loci. In the design process, the Maximum Inscribed Circle (MIC) is an index useful to evaluate the flatness of the usable workspace, the MIC is inscribed within the usable workspace and it is tangent with singular loci [4]. The Maximum Inscribed Workspace (MIW) is defined as the workspace bounded by the MIC. The MIC is characterized by the expressions:

$$x^2 + (y - y_{MIC})^2 = r_{MIC}^2 \quad (16)$$

where r_{MIC} is the radius and $(0, y_{MIC})$ is the center. For the cases when $r_1 + r_3 < r_2$, the MIC is defined by

$$r_{MIC} = \frac{r_1+r_2-|r_1-r_2|}{2} \quad \text{and} \quad y_{MIC} = \sqrt{\frac{(r_1+r_2+|r_1-r_2|)^2}{4} - r_3^2} \quad (17)$$

For the cases when $r_1 + r_3 > r_2$, the radius and center of the MIC are defined by:

$$r_{MIC} = |y_{MIC}| - y_{col} \qquad \text{and} \qquad y_{MIC} = \frac{(r_1+r_2+y_{col})^2 - r_3^2}{2(r_1+r_2+y_{col})} \tag{18}$$

with $y_{col} = \sqrt{r_1^2 - (r_2 - r_3)^r}$. Based of Eqs. (16), (17) and (18), the MIW can be expressed by using the follow expression:

$$[r_{MIW}\ y_{MIW}] = g(r_1, r_2, r_3) \tag{19}$$

where g is the the mathematical expression that computes r_{MIW} and y_{MIW} based on r_1, r_2 and r_3.

2. Stochastic Analysis

Typically the geometrical parameters of parallel robot are affected by uncertainties. Therefore, these uncertain parameters that consists in small variations around the nominal parameters introduce a variation in the solutions obtained of the kinematic model. Manufacturing tolerances include small variations in the geometrical parameters [7]. Consequently, the parameters selected in order to introduce the uncertainties in the kinematic model presented in the previous section are: the non-dimensional length of the links (r_1, r_2 and r_3), and clearances of the active joints: $\delta\theta_1$and $\delta\theta_2$).

The uncertain parameters are modeled as random variables. The corresponding uncertainties are introduced by using the follow relation:

$$a_0(\Omega) = a_0 + a_0\delta_a\xi(\Omega) \tag{20}$$

where $a_0$is the mean value of the parameter, δ_a is the dispersion level and $\xi(\Omega)$ is the unite normal random variable with Ω being a random process. The unite normal random variable is governed by a normal distribution, this distribution was selected in order to evaluate the uncertain parameters in this contribution.

The so-called Monte Carlo method combined with the Latin Hypercube sampling [8] is used to simulate the dynamic response of the robot with the considered uncertain random parameters. The Monte Carlo method combined with the Latin Hypercube permits to evaluate the uncertain response of a system by considering the fewer samples than using only Monte Carlo method. Additionally, with the aid of a convergence analysis helps determining the number of Monte Carlo samples ns to obtain an accurate result in the simulations.

3. Simulation Results

The uncertain parameters of the parallel mechanism for the inverse, forward kinematics and workspace are considered as random variables. These random variables are defined based on the Eq. (20). As it was stated previously the uncertainties in parallel mechanisms are associated with the manufacturing errors of links and the clearances of joints. The parameters of the non-dimensional length of the links (r_1, r_2 and r_3), and the clearances of the active joints ($\delta\theta_1$, $\delta\theta_2$) are defined in Table 1 in order to evaluate numerically the influence of these uncertain parameters on the kinematics. These uncertain values were selected based on previous contributions [1].

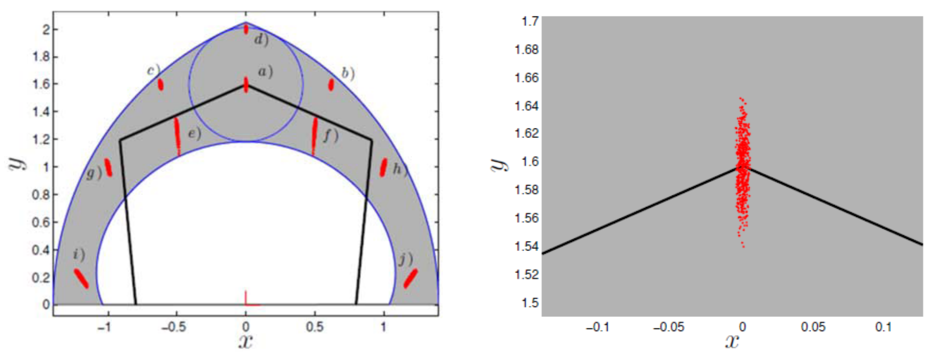
Table 1. Uncertain Parameters of the manipulator.

Parameter	$r_1(\Omega)$	$r_2(\Omega)$	$r_3(\Omega)$	$\delta\theta_1(\Omega)$	$\delta\theta_2(\Omega)$
a_0	1.2	1.0	0.8	0.25°	0.25°
δ_a	1%	1%	1%	100%	100%

The uncertain parameters of the manipulator are mapped on the kinematic model by using the Monte Carlo Simulation in order to evaluate the kinematics of mechanism in the presence of uncertainties. For this, $n_s = 150$ samples are used to compute the Monte Carlo Simulation.

3.1. Forward Kinematics

This analysis aims at evaluating the forward kinematics of the mechanism considering uncertainties in the non-dimensional lengths of the link and the clearances of the active joints that were previously described in Table 1. Consequently, the uncertainties were introduced in the forward kinematic model based on Eq. (21).



(a) (b)

Figure 2. Forward Kinematic solutions with uncertain parameters: (a) For all cases, (b) Zoom of case a).

$$\left(x(\Omega), y(\Omega)\right)^T = f^{-1}\left(\theta_1 + \delta\theta_1(\Omega), \theta_2 + \delta\theta_2(\Omega), r_1(\Omega), r_2(\Omega), r_3(\Omega)\right) \quad (21)$$

The forward kinematic with the uncertain parameters of Eq. (21) was evaluated for several poses (θ_i) within the usable workspace as presented in Fig. 2. Additionally, Fig. 2 shows the usable workspace and the MIW for $r_1 = 1.2$, $r_2 = 1.0$ and $r_3 = 0.8$.

Additionally, Table 2 presents the results of the forward kinematics which are mean and standard deviation the Cartesian position of the end effector in the x and y axis, $\bar{x}$, $\bar{y}$, σ_x, σ_y, respectively.

Table 2. Forward Kinematic with Uncertainties.

Case	θ_1	θ_2	$\bar{x}$	$\bar{y}$	σ_x	σ_y
a)	95.5181	84.4819	3.5586e-08	1.5966	0.0020	0.0193
b)	60.8802	58.0319	0.6200	1.5969	0.0040	0.0138
c)	121.9681	119.1198	-0.6200	1.5969	0.0040	0.0139
d)	78.8909	101.1091	-6.3229e-07	2.0000	0.0013	0.0110
e)	123.5349	104.7752	-0.4996	1.2648	0.0046	0.0439
f)	75.2248	56.4651	0.4996	1.2648	0.0048	0.0439
g)	154.1033	132.2085	-0.9998	0.9990	0.0071	0.0247
h)	47.7915	25.8967	0.9998	0.9990	0.0072	0.0245
i)	27.4773	-26.8307	1.1988	0.1982	0.0179	0.0260
j)	-153.1693	152.5227	-1.1988	0.1982	0.0177	0.0259

The results indicates that the uncertainties in the non-dimensional lengths of the links and the clearances of the active joints introduce a variability in the Cartesian position of the end effector of the mechanism, **p**, for all the cases considered in this analysis, this variability is quantified by the standard deviation σ_x and σ_y of each single pose. The variability in **p** is specially larger for the configurations closed to the singular loci singularities (cases: *e), f), i)* and *j)*). Additionally, it is observed that the poses closed to the limits of the usable workspace have a moderate variability with respect to the previous cases (cases: *c), g)* and *h)*). However, for the poses within the MIW, the forward kinematics exhibits a smaller variability (cases: *a)* and *d)*).

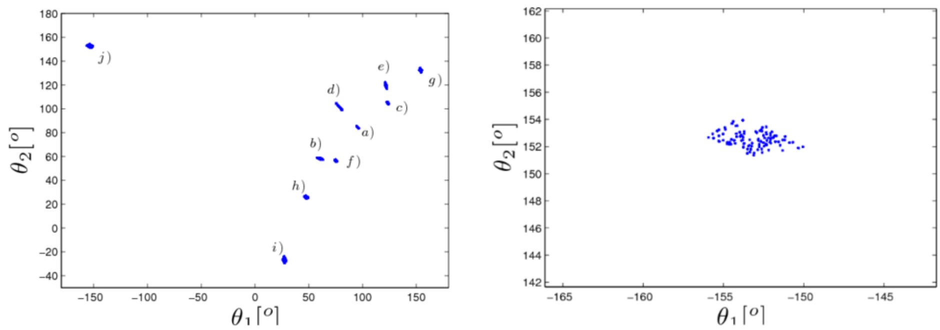
3.2. Inverse Kinematics

In this analysis the inverse kinematics is analyzed subject to uncertainties in the non-dimensional lengths of the link ($r_1(\Theta)$, $r_2(\Theta)$ and $r_3(\Theta)$) that were described in Table 1. The uncertainties were introduced in the inverse kinematic model based on Eq. (5), therefore, Eq. (22) describes the inverse kinematics with the uncertain parameters.

$$\left(\theta_1(\Omega), \theta_2(\Omega)\right)^T = f\left(x,\ y, r_1(\Omega), r_2(\Omega), r_3(\Omega)\right) \tag{22}$$

The inverse kinematic with the uncertain parameters of Eq. (22) was evaluated for the same poses that the forward kinematics was evaluated, i.e., for the poses described in Table 2. Figure 3 presents the solution of the inverse kinematics in the joint-space, the results show that all the solutions for all the poses exhibit a variability produced by the uncertain lengths of the non-dimensional links.

The results of Table 3 indicate a similar behavior of the variability of the inverse kinematics when compared to the forward kinematics of Table 2. The variability of the inverse kinematics depends on the specific pose where the model is evaluated, i.e., the variability increases at poses closed to singular loci and also for the outer limits of workspace.



(a) (b)

Figure 3. Inverse Kinematic solutions with uncertain parameters: (a) For all cases, (b) Case j).

3.3. Workspace

The usable workspace and MIW are also determined as function of the uncertain non-dimensional lengths of the links $r_1(\Omega)$, $r_2(\Omega)$ and $r_3(\Omega)$ presented in Table. 1. Based on

Table 3. Inverse Kinematic with Uncertainties.

Case	x	y	$\overline{\theta_1}$	$\overline{\theta_2}$	σ_{θ_1}	σ_{θ_2}
a)	0.0000	1.5970	95.5153	84.4847	0.3793	0.3793
b)	0.6200	1.5970	60.8415	58.0334	0.9729	0.3349
c)	-0.6200	1.5970	121.9666	119.1585	0.3349	0.9729
d)	0	2	78.8325	101.1675	1.1005	1.1005
e)	-0.5000	1.2700	123.5343	104.7780	0.3886	0.4019
f)	0.5000	1.2700	75.2220	56.4657	0.4019	0.3886
g)	-1	1	154.1027	132.2211	0.4888	0.6565
h)	1	1	47.7789	25.8973	0.6565	0.4888
i)	1.2000	0.2000	27.4687	-26.8207	0.5524	1.2538
j)	-1.2000	0.2000	-153.1793	152.5313	1.2538	0.5524

Eq. (19), the MIW with the uncertain parameters can be obtained by using the follow expression:

$$[r_{MIW}(\Omega) y_{MIW}(\Omega)] = g\big(r_1(\Omega), r_2(\Omega), r_3(\Omega)\big) \tag{23}$$

As presented in Fig. 4, the uncertainties in the non-dimensional lengths introduce an small variability in the shape of the usable workspace and the MIW, i.e., the Fig. 4 shows the plotting of all the possible realizations of the workspace with the uncertain parameters, for this reason there is an increment in the thickness of the limits of usable workspace and MIW.

The variability of the MIW is presented in Table 4. It is also observed that the uncertain parameters introduce a variability in the center and radius of the MIC, this could produce also a variability in the kinematic performance of the 5R symmetric mechanism, specifically in the Global Condition Index that is evaluated over the MIW [9].

4. Conclusions

This paper presents a methodology to evaluate the kinematic performance of the planar 5R parallel mechanism with uncertainties by using a stochastic analysis. The uncertain were considered in the non-dimensional length of the links and the clearances of the active joints, these uncertain parameters were modeled as random variables. The forward kinematics, inverse kinematic and workspace were evaluated by using the Monte Carlo Simulation.

Simulation results indicated a non-negligible variability in the kinematic model of the mechanism. Consequently, the effects produced by the uncertainties should be taken into account in order to design parallel mechanism subjected to uncertainties.

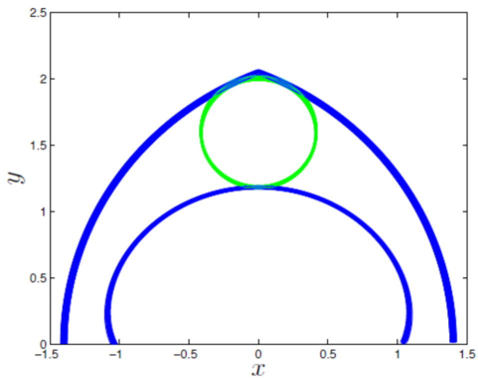


Figure 4. Usable and Maximum Inscribed Workspace with uncertainties.

Table 4. Maximum Inscribed Workspace with Uncertainties

$\bar{r}_{MIW}$	$\bar{y}_{MIW}$	$\sigma_{r_{MIW}}$	$\sigma_{y_{MIW}}$
0.4138	1.5970	0.0041	0.0085

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A Distance-Based Spectral Clustering Approach with Applications to Network Community Detection

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Abstract. Object clustering is a fundamental task in many data analysis and pattern understanding applications by providing insights into detecting the underlying structures of a large collection of samples. In this paper, we present our work on a novel spectral clustering algorithm that partitions a collection of objects using the spectrum of adistance matrix. If the nodes in a metric space can be associated with a well defined distance, the distance matrix is almost negative definite, implying that the eigenvector for the smallest eigenvalues of this matrix can be used as an approximation of the solution to a quadratic form partition problem. It is proved that this smallest eigenvalue is equivalent to the second largest singular value. Therefore Lanczos iterative algorithm can be applied to findingthe eigenvalues efficiently. We adapted this algorithm to the distributed network community detection problem using a decentralized multi-agent framework, and tested the effectiveness of the proposed approach with simulations.

Keywords. Spectral clustering, network community detection, multi-agent systems, almost negative definite matrices, Lanczos algorithm

Introduction

The rapid penetration of the mobile Internet has facilitated the growing popularity of numerous social networks and their respective applications, enabling social networks to play increasingly important roles in disseminating information and aggregating public opinions. In practice, many social networks can be effectively modeled as multi-agent systems, in which each agent only interacts locally with a small number of other agents. Within many social networks, the direct connections among the network users are established by personal ties in the first place, thus forming some possibly overlapped circles of friends in different sizes. In general, community structures exist in various networks, and the communities may evolve with memberships changing over time. Detecting community structures is a challenging problem in many scientific and engineering fields and various algorithma have been proposed to solve tis problem in different contexts[1,2]. Because there is no centralized coordinating entity existing in social networks, finding individuals with shared interest or similar pattern is not a simple task. In this paper, we intend to investigate a distributed way to allow the users to detect the networks communities consisted of similar users only using the local communications.

In the fields of data mining and machine learning, clustering is a critical step to process the data samples for the purpose of dimensional reduction or pattern detection. Though there is no universally accepted precise definition for the term clustering, clustering can be roughly treated as grouping the similar objects while separating the dissimilar ones. Many clustering techniques have been developed over years, including k-means, hierarchical clustering, density-based clustering and graph-based clustering, just to name a few. With the help of the singular value decomposition (SVD) and graph cut theory, spectral clustering makes use of the distance/similarity matrix of the dataset by examining its eigenvalues and eigenvectors. In different settings, large eigenvalues or the second smallest eigenvalue provide insights into finding cluster structures in the data[3,4]. In [3], the eigenvectors corresponding to the top eigenvalues are used to approximate the data points in a lower dimensional space and k-means algorithm can be applied on top of this result. In [4], the eigenvector for the second smallest eigenvalue of the symmetric normalized Laplacian matrix is used to partition the data into two subsets and hierarchical partitioning can be carried out within each subset. Either way, the number of clusters, k, or the quality of clusters must be predefined to make the process feasible. For example, in [5] the authors proposed an (α, ϵ) measure for the clustering quality, and [6] presented a self-tuning optimization framework to find the best-fit number of clusters. However, making assumption on the parameters is a subtle issue when the data distribution may vary greatly from case to case. Another interesting development related to spectral clustering is the decentralized versions of the spectral analysis algorithms by computing the eigen-decomposition of the weighted adjacency matrix with power iteration, QR decomposition or Lanczos algorithm in a distributed fashion[7, 9-11].

The work in this paper is motivated by the following facts: first, because of the large size of the social network and the need of privacy protection, it is unrealistic to rely on a single node of authority in the network to detect the similarity based communities and inform the rest of the network of the result[7]; second, in multi-agent systems, many collective objectives can be achieved by local interactions and simple evolutionary dynamics; finally, there are extensive applications of consensus algorithms in networked systems[8,9]. The contributions of this paper are: we propose a novel approach that makes use of the eigenvectors of the distance matrix that are corresponding to the negative eigenvalues to bisect the set of nodes recursively by introducing two partitioning quality indices for single eigenvector and cross eigenvectors, without the need to estimate explicitly the number of clusters; in the mean time, we introduce a distributed algorithm that is able to perform the spectral analysis for the distance matrix (not identical to adjacency matrix) overlaying the communication network, without exchanging the distance information between nodes.

The rest of the paper is organized as follows. In Section 1,we formulate the problem and present the definitions and algorithms used for distance matrix based spectral clustering; then in Section 2, we discuss the design of the distributed version of the Lanzcos algorithm that prepares the necessary data for each node to find the identical clustering outcome simultaneously. The experiments for some synthesized data and benchmark data are provided and analyzed in Section 3, showing the effectiveness the proposed approach. And finally in Section 4 we conclude this paper by remarking the proposed future research.

1. Problem formulation and the proposed clustering approach

In a metric space, pairwise distance is defined for points in that space, satisfying the following properties: symmetric, nonnegative and the triangle inequality. It is reasonable to assume that any user in a social network is able to find the distance between any other user and itself, provided that the users not directly interacting may observe the states and behaviors of others. We do not need the specific description of the space, as long as the distance metrics can be measured by the users on their own. Given a set of n users $\{x_1, x_2, ..., x_n\}$, and their distance measures (represented by the distance matrix A, where $a_{ij} = d(x_i, x_j)$), the clustering objective is to partition all the users into a number of disjoint subsets (assuming this number is unknown a priori), such that the members in the same subset are close in distances, and the members belonging to different subsets are not as close. One can find many different versions of the clustering approaches, in this paper, we adopt the partition cost function

$$\begin{array}{ll} \min_y & y^T A y \\ \text{subject to} & y_i \in \{-1, 1\}, 1 \le i \le n \end{array} \quad (1)$$

to find the two subsets of users, with -1 and 1 being the respective membership values. Since the above optimization problem is hard to solve, we take the similar spectral heuristics as in the normalized cut method [4]. Because the smallest negative eigenvalue of the matrix A, λ_n, is the minimum of A's Rayleigh quotient problem

$$\min_z \frac{z^T A z}{z^T z} \quad (2)$$

we will use u_n, the normalized eigenvector to find the approximate solution to (1). However, we will not take the hierarchical partitioning to find the clusters as proposed in [4], to avoid the repeated eigen-decompositions for reduced distance matrices. Instead, we wish we could find the final cluster structures with the eigen-pairs of the original A.

Lemma 1. Given a well-defined distance matrix $A_{n\times n}$, there exists a set of points of points in $n-1$ dimensional Euclidean space, $\{p_1, p_2, ..., p_n\} \in R^{n-1}$, such that. $d(p_i, p_j) = a_{ij}$.

Definition 1[12]. A real symmetric matrix $M$with zero diagonal entries is said to be almost negative definite if $c^T M c \le 0$ for all vectors $c \in R^n$ satisfying $c^T \mathbf{1} = 0$, where $\mathbf{1} = [1, 1, ..., 1]^T$.

It is proved in [12] that for a set of points $\{x_1, x_2, ..., x_n\} \in R^d$, the matrix $D = \{d^2(x_i, x_j)\}$ ($d(x_i, x_j)$is the Euclidean distance between x_i and x_j) is almost negative definte.

Lemma 2. If $A = \sqrt{a_{ij}}$ is a well-defined distance matrix, $A = \sqrt{a_{ij}}$ is also a well-defined distance matrix.

Therefore we have the following property for the distance matrices.

Theorem 1. The matrix $A_{n\times n} = \{a_{ij}\}$ is almost negative definite.

Theorem 2. A nonsingular $A_{n\times n} = \{a_{ij}\}$ has $n-1$ negative eigenvalues.

Because A has only 0's on its main diagonal, $\sum_{i=1}^{n} \lambda_i = 0$, thus we have the following conclusion.

Corollary 1. Let the distance matrix A have eigenvalues$\lambda_1 > \lambda_2 \geq \ \geq \lambda_n$, $|\lambda_n|$is the second largest singular value of A.

Denote a column of A as $a_i = [a_{i1}, a_{i2}, ..., a_{in}]^T$, $a_i \in R^n$ can be considered as a point in a high dimensional Euclidean space. Though in this paper, we will not apply the algorithms such as MDS to find a low dimensional space to embed these points, it is rather straightforward to conclude that the eigenvectors corresponding to the larger singular values of A constitute a subspace that approximates the coordinates of the related points. It is worth mentioning that the leading singular value plays a less important role than the singular values next to it in partitioning data points into clusters because the spread of its eigenvector components is relatively small due to the fact that all its components have the same sign (see Figure 1). In this sense, $\lambda_n$is the most significant eigenvector in partitioning data points into clusters.

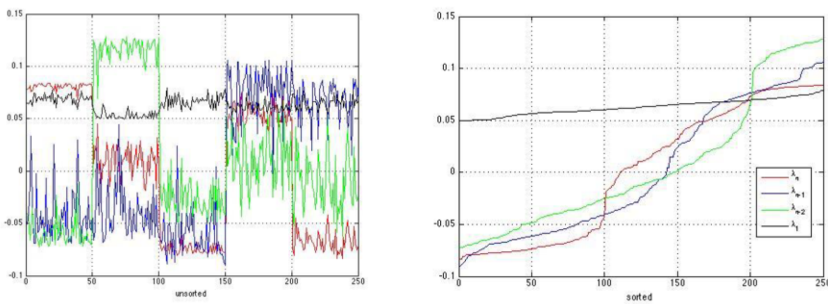

Figure 1.Unsorted (left) and sorted (right) eigenvectors corresponding to the top 4 singular values, black is for the leading one.

Corollary 2. Let a_i be the i[th] column of the distance matrix A, when the eigenvector components of the leading eigenvalue are identical, i.e., $u_{1i} = u_{1j}, i \neq j, 1 \leq i, j \leq n$, then we have the bounds $(u_{ni} - u_{nj})^2 \lambda_n^2 \leq ||a_i - a_j||^2 \leq \max_k (u_{ki} - u_{kj})^2 \lambda_1^2$.

According to the above results, we attempt to partition the set into the two based on the maximal gap between two subsets of eigenvector components. The first step is to sort the eigenvector entries of u_n, then we examine the differences between a pair of adjacent entries in the sorted eigenvector for the maximum, instead of using whether $u_{ni} > 0$ as the criterion as in the standard normalized cut[4] to avoid separating a proper cluster in the middle. However, if there are outliers located far away from the mass of data points, the maximal gap could lie between these outliers and the rest of the data, resulting in trivial clustering. To prevent singling out only the outliers, we expect that the best cut should generate practically balanced groups of data by introducing a cut quality index for eigenvector u_k.

Definition 2 (intra-vector cut quality). The cut quality for a pair of components i and j neighboring in values for a sorted of eigenvectoru_k's components is defined a

$$q_k^{i,j} = \begin{cases} \frac{|u_{ki} - ukj| \cdot |\{u_{kl} : u_{kl} \leq u_{ki}\}| \cdot |\{u_{km} : u_{km} \geq u_{kj}\}|}{r_k n^2} & \text{if } \nexists l, \text{such that } u_{ki} \leq u_{kl} \leq u_{lj} \\ 0 & \text{otherwise} \end{cases}$$

where $|\{\cdot\}|$ represents the cardinality of a set, and $r_k = \max_i u_{ki} - \min_i u_{ki}$is the range of all components in u_k. The best cut for u_k is denoted $q_k^* = \max_{1 \leq i,j \leq n} q_k^{i,j} r_k$.

In Figure 2 are the best partition results of the few eigenvectors for the smallest eigenvalues of the distance matrix, obtained with the help of the cut quality as defined in Definition 2.

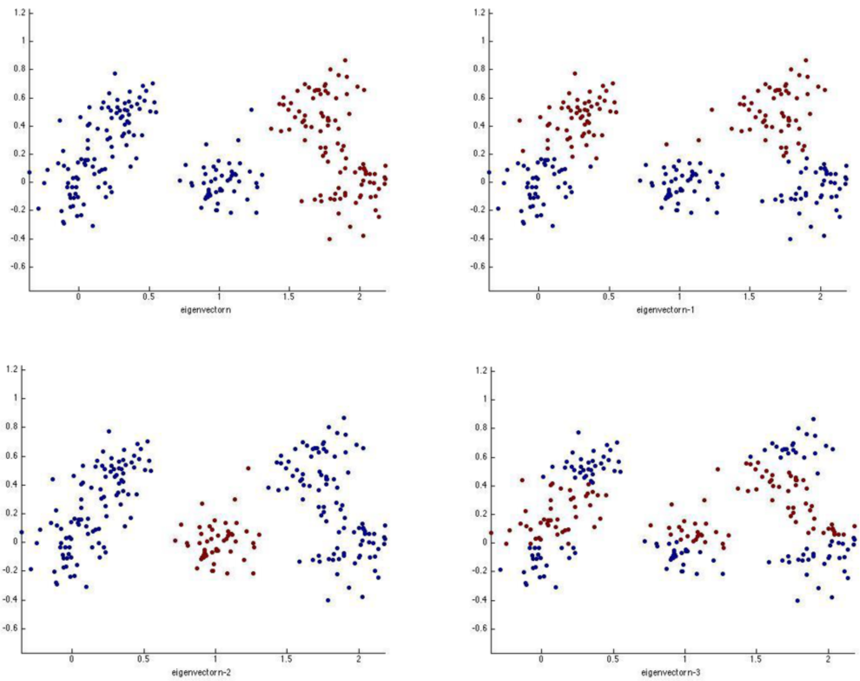

Figure 2.The best partition results based on eigenvectors for 5 Gaussian clusters.

The intersections of these partitions generated by the properly selected eigenvectors are plausible candidates for the clustering results. Since u_n achieves the optimum of problem (2), it may naturally separate data points into multiple different clusters to a greater degree of robustness than the other eigenvectors. It is attracting to take each of the eigenvectors associated with large negative eigenvalues to infer more than one cut of the dataset. As faced by other hierarchical cutting techniques, continuing to refine the cuts has to stop when certain condition is met, but this condition depends on the way to define a cluster, which is also a challenging issue in nature. In order to not explicitly specify the measurement of the cluster quality with the distance/similarity information of all points, we desire to rely only on the eigenvectors per se. Consequently, we propose a quality index to compare cuts between different eigenvectors, combining Corollary 2 and Definition 2, i.e., $q_k^{i,j} \cdot |\lambda_k|$. By doing so, we may find the successively cuts of the data with respect to a given eigenvector u_k, as long as these cuts are better than $q_{k-1}^* |\lambda_{k-1}|$, the best quality rendered by the eigenvector next to it.

Since we limit ourselves to performing data clustering exclusively dependent on the eigen-decomposition of the distance matrix, to find the exact number of clusters remains a critical challenge. We will not estimate this number in the proposed approach, instead we assume that the minimal size of a cluster (μ) and the maxmal number of clusters (M) are available a priori. Specifically we base the procedure on the following observations: first, when the eigenvalues become insignificant in magnitude, they present a pattern of disorder and will cut almost all found clusters into two, making the number of intersections nearly doubled (to be orthogonal to the eigenvectors of eigenvalues with large absolute values, see Figure 2), and lead to the poor cut quality by splitting every cluster into two subsets; second, when the magnitudes of some eigenvalues are not sufficiently small and may be able to result in acceptable partitions, they will not add new value to the whole procedure since the partitions made by the earlier cuts with respect to eigenvectors corresponding to large magnitude eigenvalues (given the sensitivity of the eigenvectors for eigenvalues close to zero, they may bring in additional noise by creating new intersections with a few data points other than only repeat what has already been found). Therefore, if we make practical assumptions on the smallest size of a cluster, as well as the maximal possible number of clusters, we then can force the clustering routine to stop if either the number of possible clusters would have been doubled and exceed the given bound, or the new cut would not give new clusters. This is summarized into the proposed algorithm as listed in Table 1.

Table 1. Distance matrix based spectral clustering algorithm.

Step 1	set μ and M initialize the cluster set as the containing only singleton, $C = \{x_1, x_2, \ldots, x_n\}$

Step 2	for i = n down to 2
	    sort u_i by the entries in descent order
	    for j = 1 to n/2 + 1
	        calculate $q^i_{j,j+1}$
	        store the current maximum to q^*_i
	    end
	end

Step 3	for i=n down to 3
	    for j = 1 to n-1
	        find j such that $q_i^{j,j+1} * \lambda_i > q^*_{i-1}\lambda_{k-1}$
	        use j found above to cut the dataset into two disjoint subsets
	        find the intersections with cardinality $> \mu$ of the subsets just found and C
	        if no new intersection is found
	            continue
	        end
	        if the number of intersections $> M$
	            go to step 4
	        end
	        set the intersections as members of C
	    end
	end

Step 4	return C

In practice, only a few eigenvectors are needed in clustering because in general the eigenvalues dwindle fast in magnitude.

2. Distributed spectral algorithm

In this section, we discuss the design and implementation of a distributed approach that allows the users in a connected social network to finish the spectral analysis of the distance matrix locally and use the eigen-decomposition results to find all the clusters independently, without collecting distance information from other users. This objective is achieved by applying average consensus algorithm to exchange the necessary data to construct the tri-diagonal matrix with the help of Lanczos algorithm[13]. It is known that by introducing a good weight matrix, a multi-agent system may reach distributed consensus or average consensus. The problem setup in this paper assumes that the communication network topology may not be coincidental to the distances determined by the other user features. We also suppose that any user is capable of finding the distances to others, but will not share the data. In order to implement the average consensus algorithm, we require each user to select $K > 0$ neighbors using the existing topology until a connected network thus built is confirmed. Once the symmetric double stochastic weight matrix gets set, the information exchange process is characterized by the following dynamics: $x_i(k+1) = \frac{1}{K+1}[x_i(k) + \sum_{j \in N_i} x_j(k)]$. It follows that $\lim_{k\to\infty} x_i(k) = \frac{\sum_{j=1}^{n} x_i(0)}{n}$.

In the iterations of Lanczos algorithm, the only information that needs the coordination of different users is the vector AQ. Because each user i has only distances measured between itself and other users, the user is able to update just the component $a_i^T Q$. Since the weight matrix is chosen to achieve average consensus, it is expected that the users will converge to the vector $\frac{\sum_{i=1}^{n} X_i(0)}{n}$, where $X_i(0)$ represents the initial vector at the user i. If a user only sets $X_{ii}(0) = a_i^T X(0)$, and all other $X_{ij} = 0$, then when the consensus is reached, each user has $X_i = AX(0)$. This process is listed in Table 2, where the inputs of maximal steps K and the error bound ϵ are required.

Table 2. Distributed average consensus algorithm for user i.

Step 1	user i selects K neighbors $\mathcal{N}(i)$, set W(i,j)=1/(K+1), if j=i or $j \in \mathcal{N}(i)$ initialize vector $X_{i,i}(0) = x(0), X_{i,j} = 0$ send $X_i(0)$ to neighbors in $\mathcal{N}(i)$ set $k = 0$
Step 2	update $X_i(k+1) = \sum_{j=ior\ j\in\mathcal{N}(i)} w(i,j) * x_j(k)$
Step 3	if $\|\|X_i(k+1) - X_i(k)\|\|^2 < \epsilon$ go to Step 4 if $k > M$ go to step 4 set $k = k+1$ go to Step 2
Step 4	return nX_i

Therefore, by applying this simple average consensus process, the Lanczos iterations can find a tri-diagonal matrix T that is similar to A (see Table 3). The eigen-decomposition for T is relatively cost-effective and can be performed by an individual user. After the eigenvalues/eigenvectors are available to each user's, the spectral clustering proposed in Section 1 will generate the same results and the users then can decide the clusters to which they belong. Lanczos algorithm may terminate at iterations fewer than n when we accept approximate solutions to eigenvectors for the most significant eigenvalues.

Table 3. Decentralized Lanczos algorithmfor AX at user i.

Step 1	user I has its distances to other users measured, and knows the size n initialize $R_0 = \mathbf{1}/\sqrt{n}, \beta_0 = 1, Q_0 = \mathbf{0}, k = 0$
Step 2	$Q_{k+1} = R_k/\beta_k$ set $k = k + 1$ apply average consensus to get $V = AQ_k$ $\alpha_k = Q_k^T V$ $r_k = V - \alpha_k Q_k - \beta_{k-1} Q_{k-1}$ $\beta_k = R_k^T R_k$
Step 3	if $\beta_k \neq 0$ and $k < n$ go to Step 2
Step 4	return $T = \begin{bmatrix} \alpha_1 & \beta_1 & & & 0 \\ \beta_1 & \alpha_2 & \beta_2 & & \\ & \beta_2 & \alpha_3 & \beta_3 & \\ & & \ddots & \ddots & \ddots \\ & & \beta_{n-2} & \alpha_{n-1} & \beta_{n-1} \\ 0 & & & \beta_{n-1} & \alpha_n \end{bmatrix}$

3. Experiments and analysis

In this section, we look at the performance of the proposed approach by applying it to different datasets. Though the porposal was first designed to solve clustering problems for mixed Gaussian data (balls in space, as shown in Figure 2), it also works for other data as long as the clusters are separated well by between-cluster distance (see Figure 3) in a properly designed distance measure. It is noted that the Euclidean distance used in Figure 3 is not a proper choice for these connected structures, nonetheless the proposal is able to find the correct clusters since the eigenvector u_n has sufficient gaps between different groups of entries.

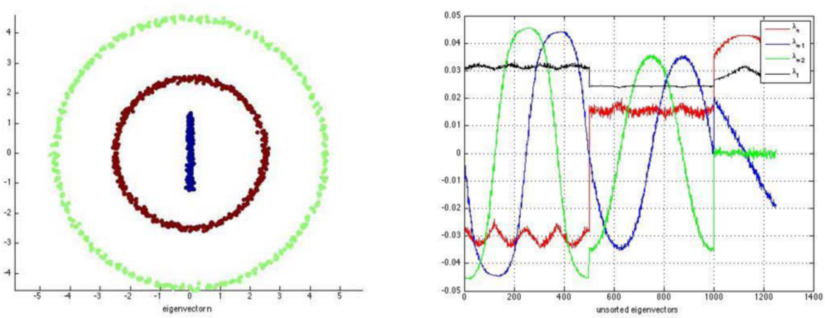

Figure 3.Clustering result using eigenvector u_n (left) and the distribution of the top 4 significant eigenvectors (right).

An interesting question is the choice of distance measures in different applications. We only considered the most straightforward way to define distance in the tests in this paper and believe more advanced distance functions will reach more accurate results. One example is the typical classification benchmark, the Iris dataset. In the test, we used the Euclidean distance of the five normalized attributes. Clearly, the proposed approach found the correct number of clusters, while Iris-versicolor and Iris-verginica got mixed results due to the closeness in distance (Table 4), and Iris-sentosa stood out of the rest.

Table 4 Confusion matrix for Iris classes.

	Iris-setosa	Iris-versicolor	Iris-virginica
Iris-setosa	98%	0%	2%
Iris-versicolor	0%	88%	12%
Iris-virginica	0%	28%	72%

The distance used in the Thackeray Karate club dataset is the pairwise shortest path with each link assigned a unit distance. To test the distributed algorithm, we applied the average consensus algorithm to pass the messages between nodes. Four clusters were found in this case, as shown in Figure 4.

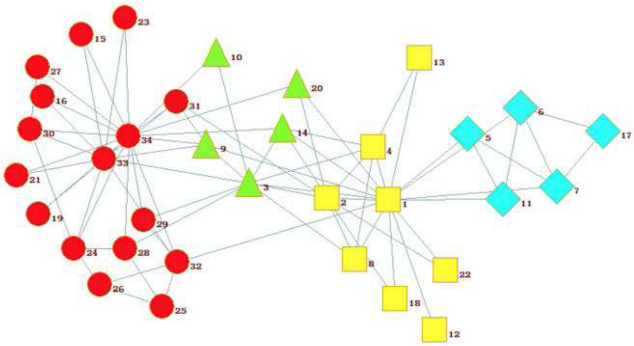

Figure 4.Clustering result of Karate club.

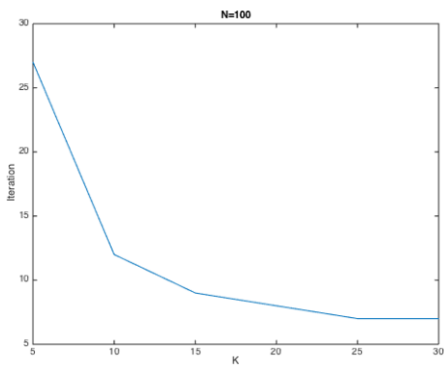

Figure 5.Convergence speed of average consensus in number of iterations, given 100 nodes.

As shown in Figure 5, the number of iterations needed to make consensus in a netwrok of 100 nodes is related to the connectivity. If each one is connected to more than 10% of all nodes, the average consensus can be reached in roughly 10 iterations.

4. Concluding remarks

The users of social networks may derive similarities based on the their attributes other than the existing connectivity, therefore, evolve into new communities with similar members on top of the communication topology is an important phenomenon observed in many of today's social network applications. We adapt the spectral clustering framework to a decentralized scheme. In general, a user may not be willing to share sensitive information with others. In order to let individual users detect the global cluster structures, we apply average consensus algorithm and Lanczos iterations to allow the users to exchange only the necessary messages.In this paper, we first proposed a distance matrix based clustering approach that makes use of its eigenvectors corresponding to the significant negative eigenvalues. We also presented ourinvestigation on evaluate the partition quality within an eigenvector (balancing the gap sensitivity and cluster size) and between eigenvectors (considering both the gap and eigenvalue). We developed the algorithm that can have multiple cuts on a single eigenvector and use the intersections of different cuts to form clusters. Then we discussed the conditions to make the partition process to terminate, using the reasonable assumptions on the minimal size of a cluster and the maximal possible number of clusters. In the simulations, we tested both synthesized and benchmark datasets, showing that the proposed approach worked effectively in both cases. However, in this paper, we suppose that the users have the global observation on others, which may not be true for all situations. Second, the partition quality is designed to separate clusters without overlapping. Third, while it is acceptable to run the distributed calculation in a synchronous way, it is much helpful to let the users detect the communities asynchronously because realistically the users may join or leave the social networks at ant time. These will be attractive subjects for our future research.

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Part 10

Digital Manufacturing and Process Simulation

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Using Business Process Models for Supporting Early Digital Mockup

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Abstract. In the present scenario of search for quality and competitiveness, many companies use digital mockups to analyze performance, manufacturability, maintainability and other characteristics of products. Virtual prototyping, or DMU (Digital Mockup), consists of an environment where one can check products and processes, exchange information and make decisions, from the conceptual design stage through detailing. However, by restriction time or lack of appropriate guidelines, many of these activities are postponed or neglected. The present work aims to define a sequence of DMU analysis activities, applicable to different industries, able to reduce rework and assist architects and designers in identifying inconsistencies in digital mockups. Modeled in BPMN (Business Process Model and Notation) standard, the process proposed herein provides analysis in areas such as assembly, security, ergonomics, manufacturing, operation and maintenance. To verify the process applicability and consistency, the context of an agriculture equipment manufacturing company was considered. In this study, aligned with the principles of DSR (Design Science Research), it was necessary to identify the flow of activities involved (i.e. product architects and designers) as well as their needs and constraints. The evaluation of process performance was done through questionnaires submitted to stakeholders. From the application of the proposed solution, it is possible to reduce the number of reworks and identify problems in early stages of product development, thus contributing to improvement of quality indicators and competitiveness of enterprises.

Keywords. PDP, BPMN, DMU, Digital Mockup.

Introduction

Virtual Prototypes have been used to reduce the number of physical prototypes during product validation [1]. Such prototypes, called Digital Mockup (DMU), are 3D models that represent the product, allowing to simulate scenarios according to considered restrictions (e.g. kinematics, dynamics, ergonomic), or can be used for various purposes and steps of the Product Development Process (PDP) [2]. When the need for a change in the product is identified, the engineer may make this change before physical prototypes. However, if some activity on the DMU is neglected (e.g. a critical constraint not analyzed in advance), chances are there will be future design rework. Therefore, for DMU to be effective, it is necessary to follow best practices along the PDP through standardized guidelines and approaches such as DFX (Design for X), thus enabling considerations of several restrictions related to products, as well as interactions with stakeholders [3, 4]. Therefore, the need for a standard language to represent the process with the activities related to the DMU is remarkable.

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The Business Process Model and Notation (BPMN) standard has been proposed in the literature as a standard representation and communication between stakeholders [5-7]. In this sense, this work aims to model a process with a sequence of activities related to DMU within the PDP in order to guide and inform designers and other stakeholders in the implementation of its activities through the BPMN standard. For the implementation of the study, in line with the principles of Design Science Research (DSR), the following sequence was performed: (a) identification of the problem and motivation; (b) definition of goals and solutions; (c) design and development; (d) demonstration; and (e) evaluation. The study considered the scenario of a multinational segment of agricultural machinery where it is intended to reduce rework due to neglected activities related to DMU.

The present paper is organized as follows: Section 1 of this paper presents a brief literature review on DMU, applied in the PDP, as well as a theoretical overview on DFX and the BPMN standard. Section 2 describes the methodological aspects of the present research, applied to the proposed process. Sections 3 and 4 bring the results of the study and the evaluation of the proposed process. Finally, Section 5 presents final considerations.

1. Theoretical Background

This section presents the basics concepts used for developing the proposed process and a brief literature review on the main applications of BPMN standard in the context of PDP and DMU.

BPMN is both a model and graphical language standard used to describe and specify business processes. The focus of BPMN is to create a pattern of communication between all involved in the processes that take place in or with companies, making the connection between the business process design and implementation of processes [5, 8].

DMU is a realistic digital representation of the layout of a product and its manufacturing processes by means of Computer Aided Design (CAD) [9, 10]. Through DMU, engineers can use geometric information, functional and kinematic analysis to assist Finite Element Analysis (FEA), Computer Aided Process Planning (CAPP) and other analysis during the PDP (e.g. manufacturability, ergonomics, maintainability) [11].

DFX is a Concurrent Engineering (CE) support approach. The letter X represents a phase of the product life cycle or a process whereby the product will pass (e.g. Assembly Design for focusing the product assembly process, which is a part of the product life cycle) [12]. The goal in DFX is to make designers become aware of the constraints involved in each phase of the product life cycle, through rules and guidelines [13].

The BPMN standard has been used extensively in various types of business, meeting specific goals of each organization, in order to reduce human error and miscommunication between stakeholders [14]. [15] study cases of application of BPMN in major European manufacturing industries, in order to support the consumer, integrate it with the company's business process, and align the PDP with the company's strategy. Currently, BPMN has also been applied as a standard to promote the visibility of processes for software and services, in the scenario of information systems, allowing for automation of decision flows of companies [14]. One of the major concerns of BPMN models are to control the quality of processes in order to add value to the company's strategy. Within this context, this paper considers DMU as a sequence of activities and a PDP sub-process, which needs to be represented in a way that ensures communication and understanding by the authors (i.e. design engineers) in all activities of the process.

2. Methodological Aspects

The work presented in this paper was based on the DSR approach [16]. This approach is related to Design Science and refers to the development of an artifact for meeting a certain goal. Such artifacts can be defined as constructions, models, methods, or instantiations. In this sense, the artifact proposed in this paper is a method characterized by a process modeled based on the BPMN standard.

The DSR approach is conducted as a set of stages: (i) problem identification and motivation; (ii) definition of goals and solutions; (iii) design and development; (iv) demonstration; and (v) evaluation, which results in a method approved to be used, suitable to the need presented above.

To develop the proposed artifact the above-presented phases are detailed in accordance with activities executed in each of them. In phase Problem Identification and Motivation a strategy based on the analysis of Engineering Change Orders (ECOs) related to a particular product was used. This product was chosen because the number of associated ECOs. With the product defined, all ECOs were collected and classified according to type of problem encountered and the system to which the component to be changed belonged. Thus, it was possible to identify which the most common problems were. In addition, through interviews with design engineers and others involved (e.g. vehicular architecture), it was possible to identify that designers subjected 3D models of components or assemblies for architecture analysis with no previous evaluation of their digital mockup or, if evaluated, only superficially. Thus, it was found that vehicular architecture activities were performed on demand. Such information afforded to conclude that this behavior generated a large accumulation of activities for architecture analysis which resulted in ECOs in later stages of the PDP.

In step Definition of Goals and Solution, it was identified that the use of a defined process could help designers during the evaluation of DMU and thus reduce rework throughout the PDP. Currently, designers are pressured to perform their activities quickly, which often prevent important analysis regarding the model to be realized. Thus, a formalized process, with each step necessary for the evaluation of a digital mockup, could serve as support and guide the designer during the execution of their activities.

In step Design and Development, the activities carried out were:

a) identification of activities flow;
b) evaluation of the DMU tool used in the company and its features;
c) new process definition; and
d) identification of the company's PDP steps related to the new process.

Through interviews, the activities normally held by the designers were initially identified. From this identification, each activity was documented and it was possible to define the flow of activities that was actually driven by the designers, for each designer performed its activities in a specific sequence. In the evaluation of the DMU tool, features available to the user were evaluated. That was done in order to find possible tool restrictions or utilities that were not being employed by the designers.

With the activities carried out in (a) and (b), it was possible to develop the proposed process, called Early Digital Mockup (EDMU). To develop it, a literature research to identify related work was initially conducted. The EDMU process corresponds to earlier analyses carried out by the designer, on partial digital product mockups. This process presents some activities that help verify possible inconsistencies in 3D models that need to be identified during CAD modelling. Then, the company´s PDP was analyzed for possible associations with respect to the proposed process.

In step Demonstration, the new process was first applied in laboratory environment. With the assistance of the DMU tool used in the company, this first evaluation was necessary to verify whether there were inconsistencies in the process. Then the process and a questionnaire was sent to some company designers for appraisal based on certain criteria such as operability, efficiency, generality and ease of use [16]. Each of them completed the questionnaire with suggestions and difficulties, which led to a review of the process. Once this step was finished, the step Evaluation took place, in which the revised process was forwarded again to some company designers so they could use it in practice.

The next section presents the proposed process, detailing each associated activity.

3. EDMU process

Based on the PDP suggested by [17], the process proposed in this study is presented in this section. During the modeling of new or revised components, verifications must be conducted at assembly level, that is, the interaction of these components with others that belong to the same assembly. Regarding the assemblies modeling, checks must be made based on the relationship between such assembly and others that are in the interface.

The sequence of activities is described below and corresponds to: i) Assembly analysis; ii) Security Analysis; iii) Ergonomic Analysis; iv) Manufacturing analysis; v) Operating Conditions Analysis; vi) Maintenance Analysis; and vii) DFX Analysis.

3.1. Assembly Analysis

Before starting the assembly analysis, the first activity of the process corresponds to open the component file and the assembly to which it belongs in the DMU analysis tool (Figure 1). Characterized as a sub-process, assembly analysis has two main activities: C*heck dynamic interference* and *Check static interference*. C*heck dynamic interference* refers to identifying possible physical interference between components related to the drive mechanisms (e.g. opening the hood) or the assembly during manufacturing. It is recommended to consult information from Manufacturing Engineering regarding the assembly sequence. *Check static interference* activity is related to the interference between components in their initial positions. It is noteworthy that these activities are associated with tolerances determined in the modeling step. Some features of the DMU analysis tool can assist such checks. If any interference is identified, the designer must return to the modeling stage and make the necessary changes.

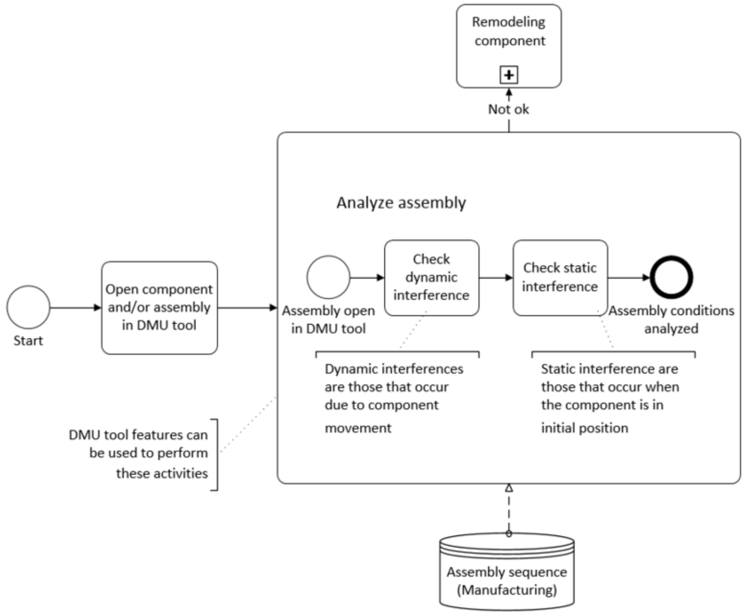

Figure 1. Assembly analysis representation.

3.2. Security Analysis

The second activity, showed in Figure 2, is related to the verification of factors that affect security. This check corresponds to identifying whether the technical functions specified to the component or assembly are met reliably and if it is possible to ensure that components do not involve risks to people or the environment. It is possible to evaluate these conditions from standards or internal standards of the company. If a risk factor is identified, the designer must return to the modeling phase and change the model.

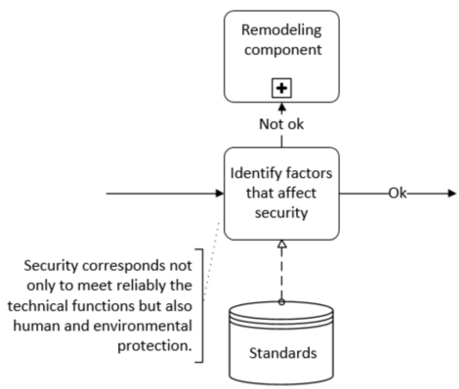

Figure 2. Security analysis representation

3.3. Ergonomic Analysis

The third activity corresponds to ergonomic analysis and is represented in Figure 3. Based on standards, the designer must verify the factors related to ergonomics. These factors involve form, aesthetics, ease during assembly and disassembly, user comfort and safety and other requirements that are directly related to the function of each component or assembly developed. By identifying that an ergonomic requirement was not met, the designer must return to modeling stage and make the necessary changes.

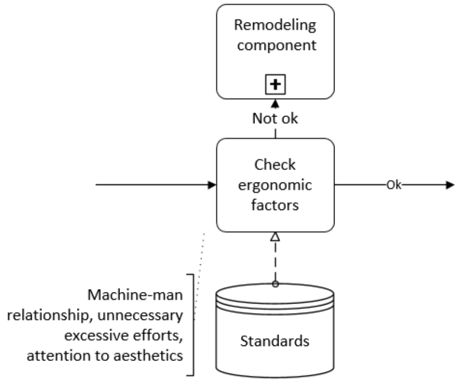

Figure 3. Ergonomic analysis representation.

3.4. Manufacturing Analysis

This activity corresponds to assess whether the modeled components can be manufactured within the company or by suppliers (Figure 4). Product Engineering should request information from Manufacturing Engineering or suppliers to assess whether there is compatibility between the developed components and the tools available. If any restriction or impossibility is detected, it is necessary to return to modeling stage or other manufacturing alternatives must be proposed.

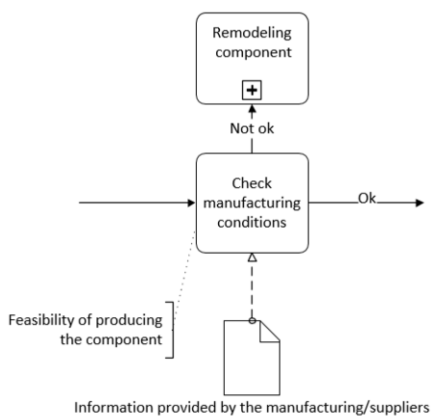

Figure 4. Manufacturing analysis representation.

3.5. Operating Conditions Analysis

This activity, shown in Figure 5, should be done so that the designer can identify the factors that influence operations (e.g. noise, vibration, and handling). The presentation of information regarding operations must be indicated appropriately (i.e. ergonomically, with appropriate colors and symbols) to avoid problems in the system itself, neighbors or other systems that generate any operational uncertainty. This check can be performed based on standards. If the representation is not in accordance with the standards the designer must return to the modeling stage to perform the correction of the model.

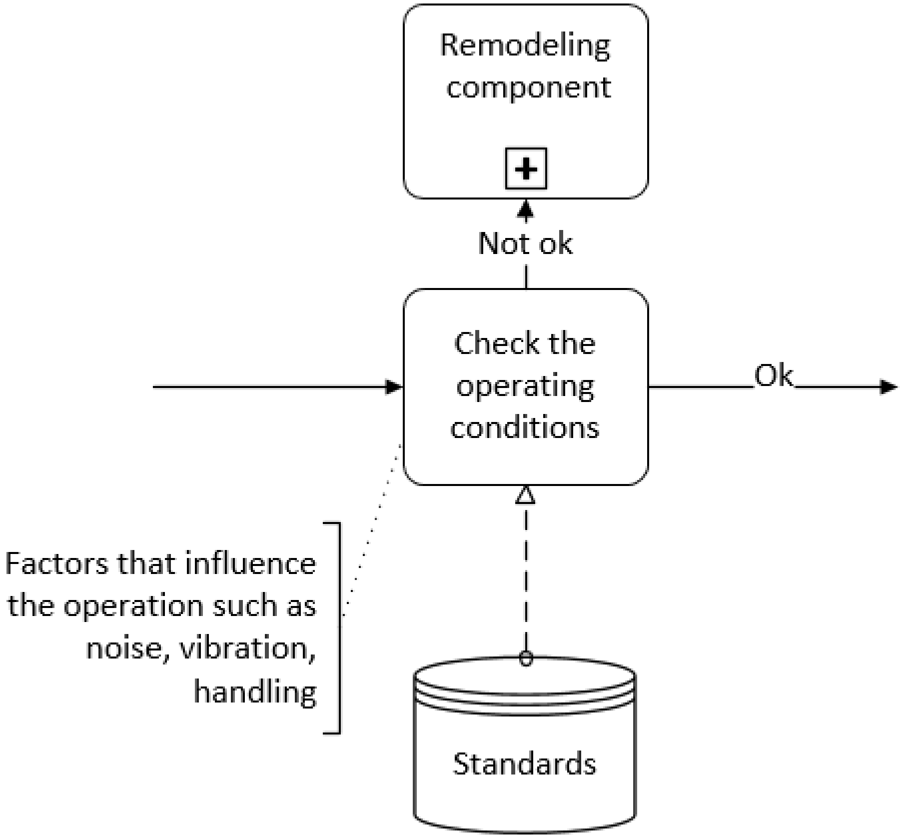

Figure 5. Operating conditions analysis representation

3.6. Maintenance Analysis

Check the maintenance conditions is the activity that corresponds to evaluating the assembly and disassembly of the component or assembly for simplifying maintenance procedures and inspection (Figure 6). This assessment should be made based on standards and on information provided by Manufacturing Engineering and Product

Support. If the designer identifies potential improvement opportunities or potential problems that may be related to maintenance, he should return to the modeling step.

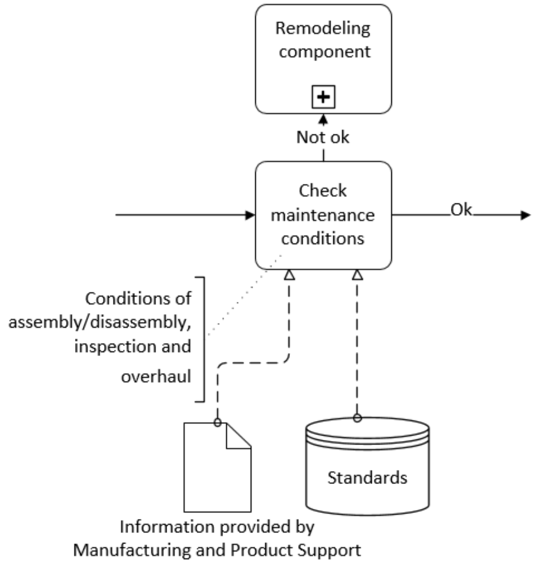

Figure 6. Maintenance analysis representation.

3.7. DFX Analysis

The last process activity is represented in Figure 7. It corresponds to the analysis of the model with respect to ease of assembly, maintenance and manufacturing and the possibility of cost savings [18]. It is important that design engineers address those analyses at this stage of product development. Thus, alternatives that are often found in later steps (e.g. physical prototyping, manufacturing) can be raised. To guide the designers in the implementation of this activity, a checklist was associated.

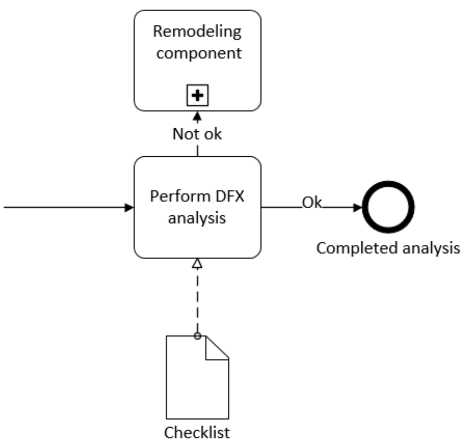

Figure 7. DFX analysis representation.

4. EDMU Process Results and Evaluation

After performing the sequence of activities presented in the previous section, the design engineer has a revised and more consistent model, which can be forward to vehicle architecture analysis. Such analysis corresponds to an important PDP stage of the company.

To validate the process some activities were conducted, according to the criteria presented in section 2. Initially, the distribution of questionnaires to stakeholders made it possible to assess the feasibility of the process. The questions presented in the questionnaire were, as follows:

1. Is the process applicable to any project?
2. Is the process clear about the sequence and activities?
3. Is there any inconsistent activity?
4. Is there any activity that could be inserted in the process?
5. Does the use of the process add complexity to the job?

Stakeholders who answered to the questionnaire belonged to different teams of Product Engineering and the responses obtained from this questionnaire, in general, converged. They confirmed the applicability of the process, consistency about the sequence of activities and pointed out that there was no activity incoherence. Question number 4 was the one that most returned different answers, not only with suggestions for activities but also possible inputs for the activities already submitted. Great part of the stakeholders stated that the use of the process would not bring greater complexity to the execution of the work, but pointed out the lack of time as an obstacle to a full implementation.

Through the responses and an assessment carried out in the laboratory environment, the initial process was revised. The DFX analysis activity was a suggestion accepted and inserted in the process, as can be seen in section 3. Thereafter, the new process was again sent for designers to use in practice. Thus, it was possible to identify that the process was applicable to any project and was easy to use. Furthermore, the use of a formalized process shows improvement in process efficiency, since it allowed the reduction of rework.

These results proved that the process met the operability, efficiency, generality and ease of use criteria. Therefore, in addition to rework reduction, other benefits of using the process were evidenced. Among them, the increase in aggregated value associated with project activities, encouragement for integration among stakeholders, increased reliability of digital mockup and therefore the final product, and the standardization of a sequence of activities that helps in project management.

5. Final Considerations

The present study allowed to recognize that even great companies face problems while conducting activities throughout the product development process. Decisions are made according to random criteria, for formalized procedures are nor followed. Thus, the possibility of someone to neglect important activities may generate non-conformity problems. In the scenario presented in this paper, these problems can cause rework and failure to execute important activities, which consequently imply new engineering change orders.

One of the challenges of this study was to fully understand how the flow of activities was conducted at the partner company environment. It was important to know what the difficulties and needs of designers were to thereby, develop a coherent and complete process with activities that actually contribute to reducing rework.

One possible sequence for this study may be related to the development of other processes to formalize the flow of activities in relation to subsequent activities. Moreover, associating this process to a support tool would ensure better use of the process. Thus, it would be not only a guide, but also a set of obligatory steps. The EDMU process can also be used or adapted to other companies, as it was developed with the purpose of being used in any project.

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Using Simulation Method for Designing ADAS Systems for Electric Vehicle

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Abstract. Since 2012 the Smart Power Team has been actively participating in worldwide competition – the Shell Eco-marathon. From the beginning, the team has been working to increase driver's safety on the road by developing Advanced Driver Assistance Systems. This paper presents unique method for designing ADAS systems in order to minimize the costs of the design phase and system implementation and at the same time to maximize the positive effect the system has on driver and vehicle safety. The described method is based on using virtual prototyping tool to simulate the system performance in real life situations. This approach enabled an iterative design process, which resulted in reduction of errors with almost no prototyping and testing costs.

Keywords. ADAS, simulation method, virtual prototyping, electric vehicle, PreScan

Introduction

Conducting the design process of Advanced Driver Assistance Systems (ADAS) in an optimum way requires a specific approach to defining and solving problem [1, 5]. Profound research and analysis have to be carried in order to prepare well for this task. Sometimes it is impossible though, to identify and avoid certain mistakes in the process, without using a prototype [6, 8]. Currently there are more and more tools available for engineers that enable creating virtual prototypes and therefore optimizing the design process in terms of its effectiveness and fault minimization [2, 4] . Nevertheless in order to use these tools efficiently there needs to be a proper approach to design process adopted. The aim of this article is to present the approach to ADAS design process, which includes the use of simulation methods and virtual prototyping. Preceding the actual method description, there are some considerations included, whether there are reasonable grounds for using virtual prototyping tool and what other tools should be considered before making the final decision. Following sections of this article include the method description and the use case – design process of Blind Spot Information System for urban vehicle.

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1. Consideration of the retionale for using virtual prototyping tool

1.1. Defining the needs

First step that needs to be taken in ADAS design process is needs definition. What must be identified are the problems that a driver is facing and possibilities of finding the right solutions for them. The most effective way of finding them are interviews with actual drivers and analysis of traffic situations of great risk for driver, vehicle or third parts safety. What needs to be considered in this step are the most common conditions in which the driving task is performed [1, 2]. For vehicles dedicated for specific goals, such as competitions, these conditions can be described very precisely, which enables finding most actual problems and most effective solutions [4, 5]. The choice of prototyping tool, which would be used in further steps, needs to be based on tool possibilities in terms of reflecting reall environmental and situational conditions.

1.2. Defining the external constraints

Before making a decision about using virtual prototyping tool for ADAS design, it needs to be considered, whether a need for using such a tool actually exists. In order to answer this question the external constraints must be considered and it must be verified how the design process will be affected by using simulation methods.

There are multiple constraints, that must be taken into account, when thinking about designing ADAS. One of the most basic ones are: costs, time and quality. It is accepted that only two of these three constraints can be fulfilled at the same time.

1.3. Discussion of possible ADAS design methods

There are various methods of ADAS design available and it is crucial to choose the one that fits best the needs of the project. ADAS can be designed in following ways:

1. No prototype – which does not enable to verify its performance in real life situations until the system is implemented,
2. Virtual prototype – which, accordingly to chosen tool, enables to simulate the natural conditions in very but not perfectly accurate way, generates low costs and enables the iterative design process,
3. Real prototype – which enables absolute verification, but has also many drawbacks such as costs, production and construction time, difficult interaction.

When considering the virtual prototyping tool the above mentioned aspects must be included.

2. Design method

2.1. Project analysis

In order to minimize the need for changes in further steps of the ADAS design process it is recommended to define all internal constraints before working on an actual model. This approach enables to precisely set the goal of the designed ADA system and define the required constraints early enough to be included in the model. Using a virtual prototyping tool for such complicated systems as ADAS requires splitting considerations about the whole system into subsystems.

2.2. Designing and testing

Testing part of designed system is a step that must not be neglected. Thorough tests are the last step before real system implementation, that allow error detection without generating additional costs in manufacturing process. Correctly conducted testing enables also very accurate error identification and makes their correction easier.

In order to properly define test cases for ADAS virtual prototype testing, three system separate aspects must be considered, in which an error could appear:

1. Data processing – software
   - 1.1. What are the system inputs?
   - 1.2. What are the system outputs?
   - 1.3. What is the path of converting inputs to outputs?
   - 1.4. What values are independent from the system design and may not be tested?
2. Functional requirements – UI and usability
   - 2.1. What the system is supposed to do?
   - 2.2. What information is it supposed to communicate to the driver?
   - 2.3. What must the system not do?
3. Modesl design – the idea
   - 3.1. How should the system work?
   - 3.2. What inputs and outputs should it accept/generate?
   - 3.3. By what functions is the system described?

Such analysis enables to create test cases sheet that should be used in test experiments outcome evaluation. Only when every test case will end successfully i.e. the values will be corresponding with template values and the visual verification will be fulfilled, the system can be implemented.

For correct testing process of ADAS virtual prototype it is also needed to cover all possible situations in simulations, in which an error could appear. The test experiments should include both typical traffic situations of a higher risk and non-risky situations in order to test the system against false alarms.

3. Use case – BLIS for urban electric vehicle

The above described design method was used in design process of Blind Spot Information System (BLIS) [6, 14] for urban electric vehicle – Bytel [3, 4, 5] (Figure 1). Bytel is a vehicle created to participate in Shell Eco-marathon (SEM) [3, 11] competitions, the event which aims to encourage design of highly efficient vehicles by students and scientific organizations. Bytel has participated in SEM in 2014 and 2015 in two power source categories battery electric and hydrogen (hydrogen fuel cell) [9, 10, 12].

Figure 1. Bytel vehicle during Shell Eco-marathon race in Rotterdam (2015).

The steps described above were taken in order to successfully finish the process at minimal time and maximum quality, keeping the costs reasonable at the same time.

3.1. Considerination of the rationale for using virtual prototyping tool

The decision to develop BLIS for urban vehicle was made based on low viewing range, which is characteristic for common conditions for this kind of vehicles [4, 5], i.e. vehicles designed specifically for Shell Eco-marathon competitions. BLIS is the system that informs the driver about vehicles coming from the back of the vehicle, which are invisible to the driver due to its low viewing range. The need of creating such a system has been recognized based on analysis of many accidents and dangerous situations happening during the race and also after discussing the problem with drivers participating in SEM.

While deciding to use virtual prototyping tool, the crucial reason for using it was the necessity for parallel construction process. As the vehicle was still in development phase during the design of BLIS, there was no possibility of using real prototype in order to conduct tests and work on data processing improvement. This is equivalent to accepting time as the main external constraint that applies to this project.

The second constraint was quality of the system – as the vehicle purpose was to take part in SEM competition, i.e. in the race, it was considered extremely important to provide the driver with ADAS of best possible quality. The point was to help the driver keep safe and avoid active or passive participation in accident.

Last but not least, the adequate tool needed to be chosen for designing and conducting BLIS simulations. There were a few virtual prototyping tools especially dedicated to ADAS design which were considered. The final choice was TASS PreScan [13] due to its wide range of predefined sensors, very friendly user interface and great visualization capabilities.

3.2. Project analysis

3.2.1. Defining the internal constraints

Following the described method the first step after recognizing the need of creating BLIS and defining the external constraints, that lead to decision of using virtual prototyping tool, was defining the internal constraints of the designed system.

Following the described method, the first step after recognizing the need of creating BLIS and defining the external constraints, that lead to decision of using virtual prototyping tool, was defining the internal constraints of the designed system:

1. The system cannot affect actively the breaking and/or steering system.
2. The system functions must be restricted to information/warning functions.

The self-imposed constraints of the project were also directly connected to Shell Eco-marathon assumptions, as the purpose of Bytel vehicle was to achieve best result possible in this competition (SEM is about developing highly energetic vehicles). In order to satisfy this goal there were the following constraint sets:

1. The weight of the system must be minimized.
2. The system should not consume relevant amount of power.

These constraints enabled to define the general approach to designed system.

At this point the decision regarding system parts has been made, which was vital to create the system model in TASS PreScan. There were two possible kinds of sensors considered: photoelectric sensors and lidar. Both kinds of sensors are available in predefined form in TASS PreScan, with a possibility of their configuration in very wide range. The decision was made to use Hokuyo lidar (Fig 2).

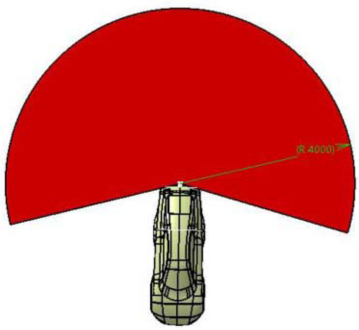

Figure 2. Hokuyo lidar in BLIS.

What was crucial when deciding about rejecting the photoelectric sensors option was their low resistance to environmental conditions – a high risk of inaccurate results was identified. Also, in case of photoelectric sensors, there would be a need for using at least 9 sensors in order to cover sufficiently the area invisible to the driver. Whereas, there was only one lidar needed to enable scanning this range.

3.2.2. Splitting system into subsystems

Defining the subsystems and splitting the system into them when developing a virtual prototype, made it not only easier to follow the design process step by step, but also made a good ground for tests analysis.

The main determinant of dividing line which would be used for splitting the system were assumed real life subsystems. This means, that it was needed to consider the separate parts of BLIS system, as they were meant to be implemented in real life. This is why the decision was made to consider BLIS in two subsystems: data processing subsystem and control subsystem.

The data processing system included also a verification subsystem, which uses the data generated in PreScan in order to compare the values between ideal ones and the ones that were received via data processing based on assumed input values. An example of such comparison can be seen in Fig. 7.

3.3. Designing and testing

The process of ADAS designing itself in TASS PreScan consists of four steps:

1. Building scenario
2. Modeling sensors
3. Adding control system
4. Running the experiment

The conditions for which the vehicle was designed were very specific, as they were determined in details by Shell Eco-marathon competition organizers [11]. This made it possible to create a virtual prototype with maximum coherence with real life conditions. The model of the environment can be seen in Fig. 4 [4, 5].

In the environmentprepared in this way, the vehicles and their trajectories were added. TASS PreScan allows to define the vehicle dynamics in very precise way which makes the simulation results extremely valuable. When assigning trajectories, the point was to imitate the real SEM conditions as accurately as possible, so all the dynamic parameters were designed adequately to real life scenario (Fig. 5).

The next step was modeling the sensors. Using virtual prototyping tool it was possible to model Hokuyo lidar in highly precise way – there could be location, orientation, range and beam specifications modeled (Fig. 3).

The next step was modeling the sensors. Using virtual prototyping tool it was possible to model Hokuyo lidar in highly precise way – there could be location, orientation, range and beam specifications modeled.

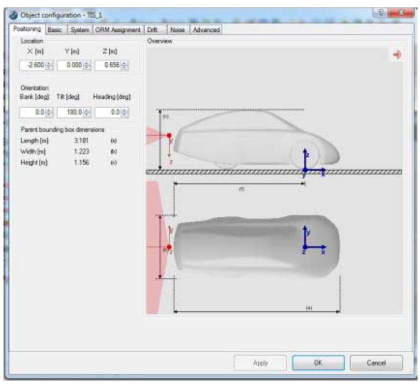

Figure 3. Modeling Hokuyo lidar in BLIS.

3.3.1. Data processing and control systems

First step in creating control system for BLIS was preparing the flow diagram of the system (Fig 6). This enabled us to make accurate work time estimation and reasonable task schedule and order.

The diagram included splitting the whole system into data processing system and control system. The control system consists of BLIS core system and visualization system. Each of these parts was crucial in terms of system final performance.

Data processing system converts the values received from lidar into input values of actual BLIS core system. The advantage of using virtual prototyping tool was particularly noticeable in this step, as PreScan gave the possibility to verify the end values and compare them with reference values (Fig 7).

The BLIS core system outputs two kinds of data regarding the detected vehicle that approaches from behind: the data defining risk level (i.e. distance) and position. This information is then passed to visualization system, which is responsible for generating correct inputs for each of LEDs that are used to inform the driver about current situation.

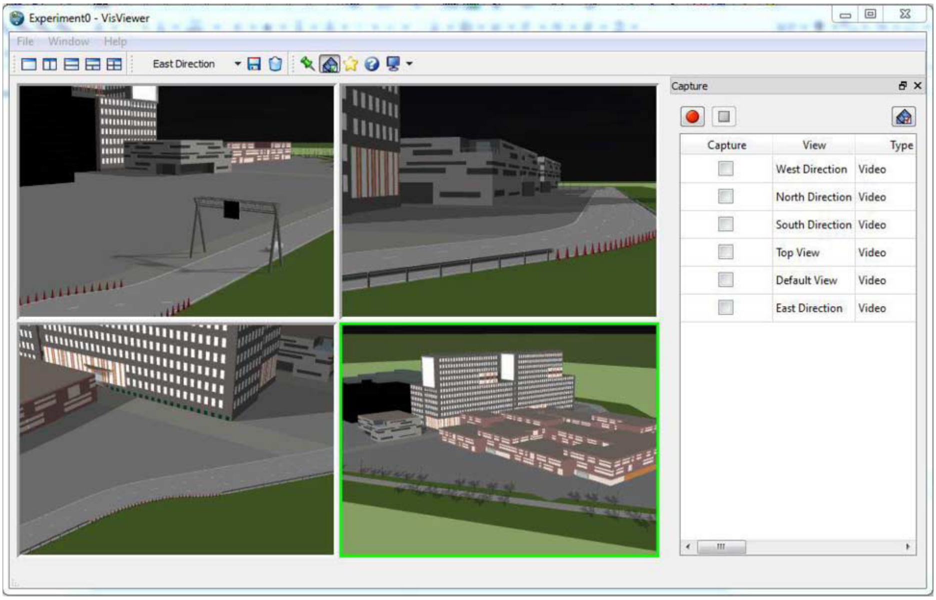

Figure 4. Model of the environment made in TASS PreScan.

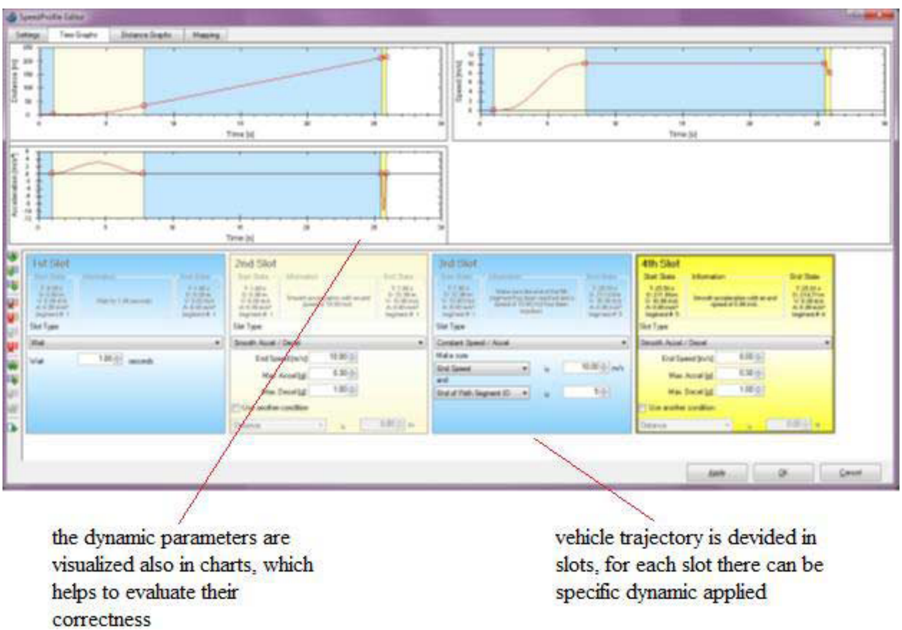

Figure 5. Speed profile for overtaking vehicle.

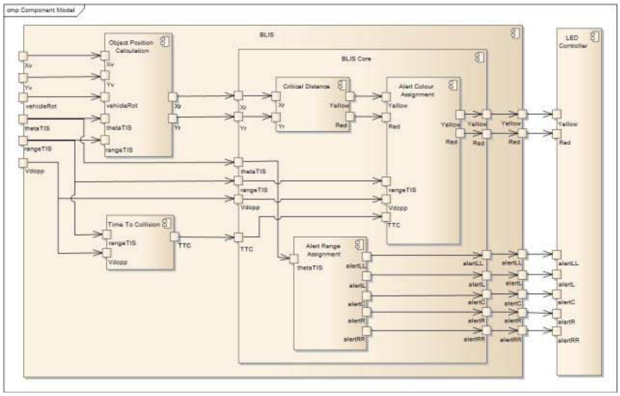

Figure 6. Flow diagram of BLIS on Bytel vehicle.

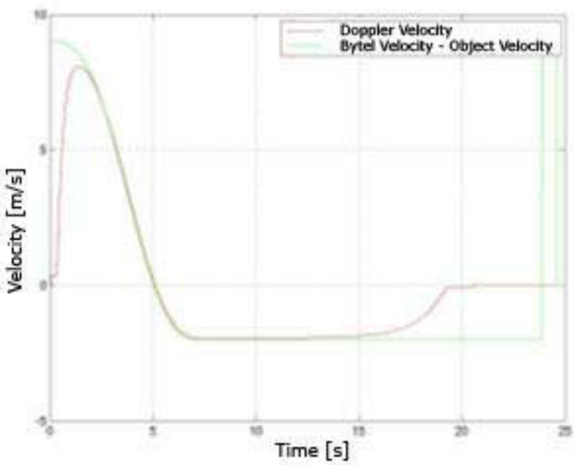

Figure 7. Comparison of two values – ideal one (Doppler Velocity) and the one achieved in data processing (Bytel Velocity – Object Velocity).

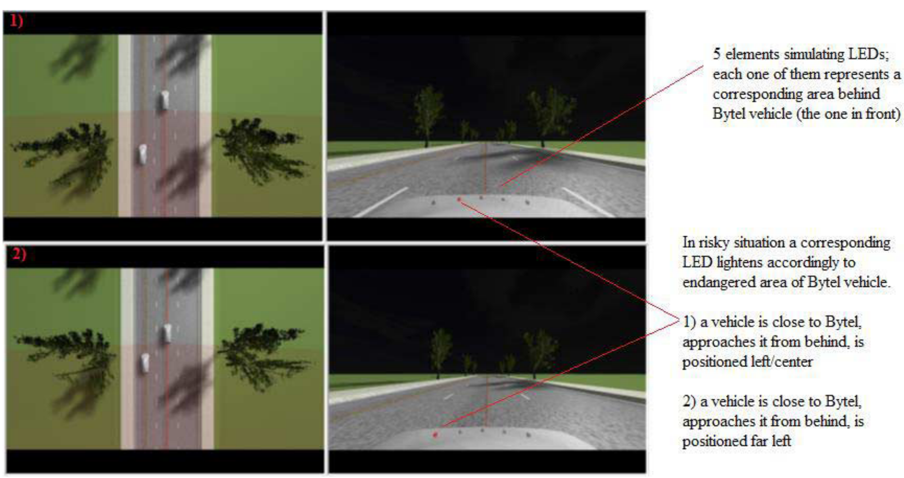

Figure 8. Example of visual verification.

3.3.2. Testing

The testing part has been conducted in three areas: calculation verification, visual testing and numeric tests.

Calculation verification has been made by comparing the end values of data processing part of the system with reference values that were generated directly by the software.

Visual testing was based on checking the behavior of virtually modeled elements that imitate LEDs meant to be used in real life system. What was tested is the color of the alert (yellow for low risk situation, red for high risk one) and the area for which the alert was generated (the blind spot was divided into 5 separate areas, each one was represented by individual LED) (Fig 8).

Numeric tests were needed in order to verify if the designed system works accordingly to project assumptions and idea of the designer.

3.4. Conclusions on BLIS design process

BLI system for urban electric vehicle has been successfully designed with the use of virtual prototyping tool and simulation method. The tests' results were correct and, although the real life system has never been build, the system design is finished and can be implemented at any moment.

4. Consideration of possible improvements

Although the final result of applying the described method was satisfying, there were still areas for the improvement. First of all there should be stronger emphasis put on the iterative approach to design, combining design phase with testing phase.

What also would be of a great value is system real life implementation and comparison of real life values with outputs received from simulation. This could help to identify the areas where the described method does not prove correct or needs improvement.

Similiarly as TASS, PreScan enables also creating experiments for various weather conditions and it would be valuable to test the designed system for different atmospheric conditions. It is especially true for systems that assume using sensors which output values are weather-dependent (eg. sonars, lidars).

5. Conclusions

The described method of Advanced Driver Assistance System design, with the use of virtual prototyping tool, has been applied in real life project. The outcome of taking this approach can be evaluated as successful, as the reasons for using this kind of method has been proven and the final results has been considered satisfying.

Using simulation method in ADAS design shortens work time, makes the iterative approach to design easier and faster, enables early error detection and identification as well as encourages parallel work. Therefore it can be stated, that using this method results also in costs reduction and system quality improvement.

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Active Vibration Control Applying Fuzzy Logic in a Flexible Rotor Using Electromagnetic Actuators

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Abstract. In the last few years, new methods to perform active vibration control were proposed and developed with the purpose of handling with several dynamic problems. These researches are motivated by the necessity of a safer and more efficient performance in the operation of mechanical systems (industrial applications). There are several types of actuators available for the active vibration control, the current work is dedicated on the Electromagnetic Actuator. This actuator uses electromagnetic forces to control the rotor without mechanical contact. And it is represented by a non-linear model, which justifies the control by Fuzzy Logic. In this work, the aim is to attenuate rotor system vibration by Fuzzy Logic based in Takagi-Sugeno model, the control is achieved using the linear quadratic regulator. Finally, the simulation results demonstrate efficiency of the methodology, which can be seen in the reduction of vibration amplitude.

Keywords. Active Vibration Control, Electromagnetic Actuator, Fuzzy Logic

Introduction

Nowadays, it is noticed an increase in the number of research works related to the development of techniques for the active vibration control (AVC). In [1] the AVC techniques are classified into two main categories: the active vibration control, which consists on applying lateral loads that oppose to the loads due to vibration; and the active equilibrium, which consist on the redistribution of the mass through the rotor done by actuators in order to stabilize the rotor.

The rotor was modeled by finite element method, in [2] is detailed the discretization process and provides the elementary matrices to obtain the global equation of motion. A model reduction is performed in order to enable the system for the control simulation, it is concerned with achieving an approximate model, and involves a trade-of between the order of the model and its ability to duplicate the behavior of the full order model within a given frequency range [3].

Several authors [4-7] have proposed different ways to handle with the non-linearity of the actuator. In [4] it is used an inverse model of the electromagnetic actuator to control a flexible beam and the control force is used to determine the electric current

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that activated the EMA. In [5-6] it is used the Fuzzy Logic based on local models to solve non-linear systems. In [8] a parallel distributed fuzzy controller was used to control pitch and yaw angles in a helicopter-like twin-rotor system.

In order to attenuate the rotor vibration, it is used the linear quadratic regulator (LQR) to solve the Fuzzy Logic, considering the Takagi-Sugeno model. This approach was used in [5] to control ball beam system, magnetic levitation system and the position of the leg for paraplegic patient. In this work, the electromagnetic actuator (EMA) is used to control the dynamic behavior of a flexible rotor. In this sort of actuator, the difficulty is related to its non-linear behavior. This procedure is used to solve the actuator non-linearity problem so that the system can be controlled.

1. Rotor Model

The rotor model presented was achieved using 32 Timoshenko beam elements, shown in Figure 1. The disks D_1 and D_2 are in nodes 13 and 22, the bearings M_1 (hybrid bearing) and M_2 are in the nodes 4 and 31, and the measuring plane is considered at node 8.

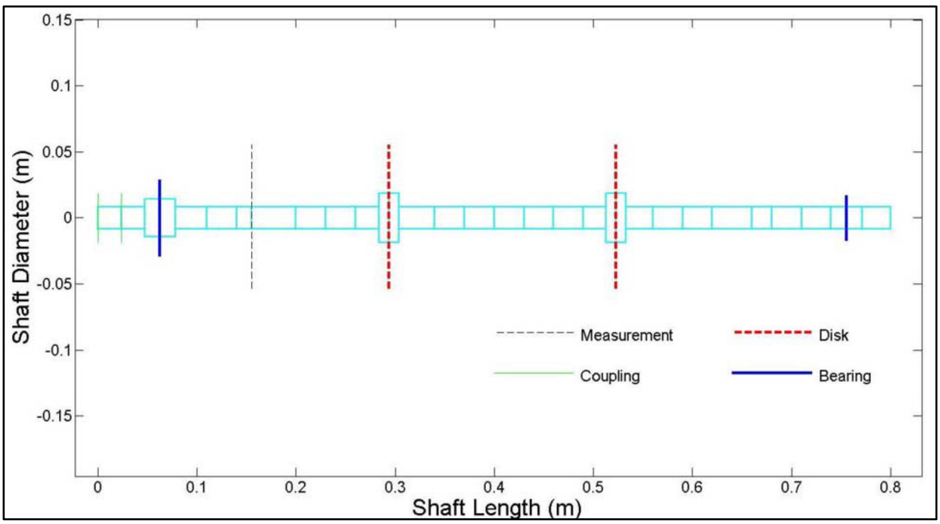

Figure 1. Rotor Sketch (From [7]).

The motion equation of the flexible rotor was obtained using Finite Elements Method and can be written in the global matrix form as follows:

$$[M]\{\ddot{x}(t)\}+[C_b+\dot{\phi}C_g]\{\dot{x}(t)\}+[K]\{x(t)\}=\{F_u(t)\}+\{F_{EMA}(t)\} \quad (1)$$

with,

$$F_{EMA}=\frac{N^2 I^2 \mu_0 af}{2\left((e\pm\delta)+\dfrac{b+c+d-2a}{\mu_r}\right)^2} \quad (2)$$

$$F_u = m_u r \dot{\phi}^2 \sin(\dot{\phi} t) \tag{3}$$

where *{x (t)}* is the generalized displacement vector. *[M], [K], [C_b],* and *[C_g]* are the well-known mass, stiffness, viscous damping (which may include proportional damping), Coriolis (regarding the rotational speed), $\dot{\phi}$ is the angular speed,*{F_u (t)},* force due to mass unbalance which comes from the modelling developed in [2], m_u is the mass of the unbalance at a radial distance *r* from the rotational axis. The contribution of the electromagnetic actuator force, *{F_{EMA}(t)}* was added to the resultant force.

The hybrid bearing is formed by four electromagnetic actuators, two for control direction *x* and two for *z* direction to be able to apply loads in both positive and negative directions for this axes, given that the actuators only apply attraction forces and each actuator act independently [7]. Figure 2 presents the hybrid bearing model (bearing with four EMA) and Figure 3 shows a schematic model of each actuator.

The parameters that define the coil geometry (*a, b, c, d, e, f*) are shown in Figure 3; μ_0 and μ are the vacuum permeability and the permeability of the material respectively, μ_r, the relative permeability, is the ratio μ/μ_0 and it is achieved by experimentation. δ is the variation of the clearance due to rotor vibration in the electromagnetic actuator position.

Coil parameter as [7]: *μ_0=1.2566 x 10^{-6}H/m, μ_r=700, N(coil turns)=250, a=9.5 mm, b=38.0 mm, c=28.5 mm, d= 9.5 mm, f = 22.5 mm e=0.5 mm.*

Table 1 presents the physical properties of the rotor.

Table 1. Physical Characteristics of the rotor-bearing system as [7].

Rotor		Bearings	
Property	**Value**	**Property**	**Value**
Shaft Mass (kg)	4.1481	k_{x1} (N/m)	7.73 x 10^5
D_1 Disk Mass (kg)	2.6495	K_{z1} (N/m)	1.13 x 10^5
D_2 Disk Mass (kg)	2.6495	k_{x2} (N/m)	5.51 x 10^8
D_1 Disk Thickness (m)	0,100	K_{z2} (N/m)	7.34 x 10^8
D_2 Disk Thickness (m)	0,100	C_{x1} (N.s/m)	5.7876
Shaft Diameter (m)	0.029	C_{z1} (N.s/m)	12.6001
Young Modulus (GN/m^2)	205	C_{x2} (N.s/m)	97.0231
Density (kg/m^3)	7850	C_{z2} (N.s/m)	77.8510
Poisson coefficient	0.3	-	-

Figure 2. Hybrid Bearing (From [7]).

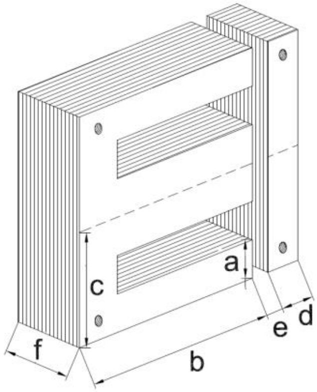

Figure 3. Ferromagnetic Circuit (From [7]).

2. Methods

The control strategy is shown in Figure 4. It comprises the excitation forces applied to the system, the finite element model and the actuator control forces. The control works receiving data from the finite element model, in the space state form, then, the Fuzzy Logic associated with local controllers calculate a current to activate the electromagnetic actuator. Notice that y is dependent of the rotor position. In Figure 4, x refers to the state vector and y to the output vector. Both the system output and electric current contribute to F_{EMA}.

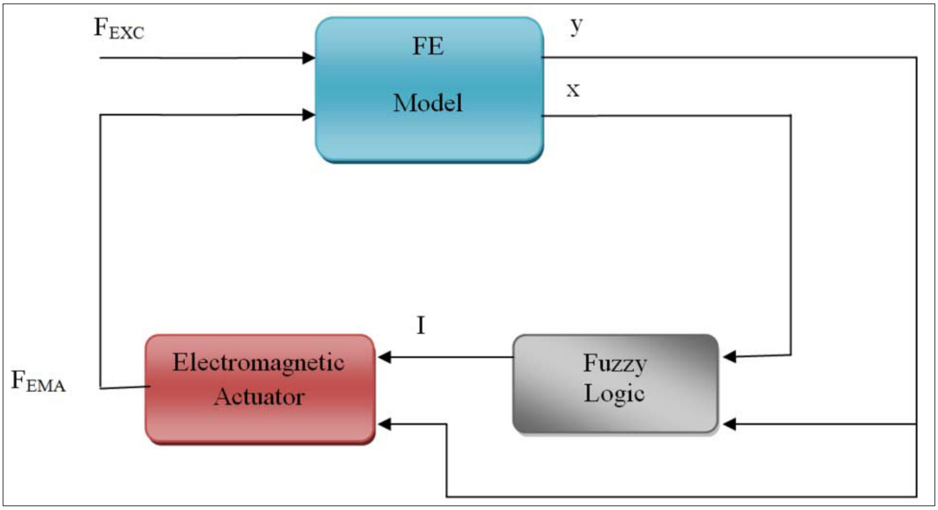

Figure 4. Control Strategy by Fuzzy Logic.

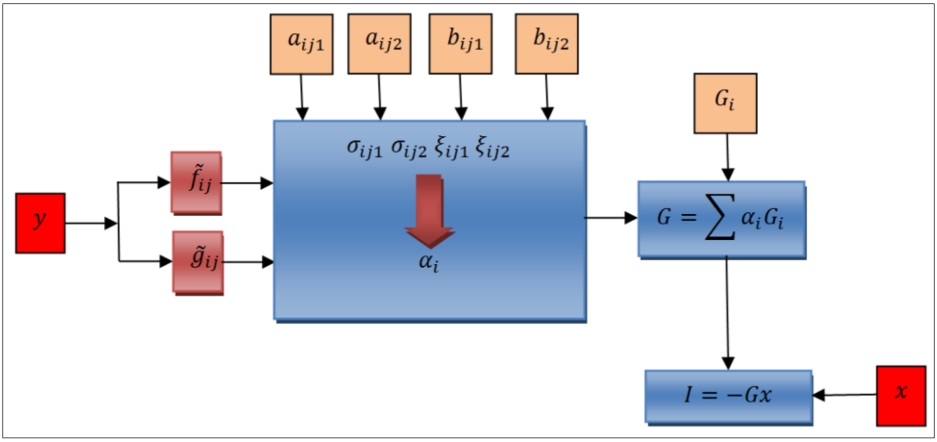

Figure 5. Fuzzy controller using the TS model (adapted from [5]).

The structure of the proposed Fuzzy controller is shown in Figure 5. The terms $\tilde{f}_{ij}$ and $\tilde{g}_{ij}$ are the nonlinear functions in the system, which in the present work are the electromagnetic forces in direction x and z respectively, obtained by inserting the maximum value for δ in Equation (2), which will provide the maximum and minimum values in the following equations:

$$a_{ij1} = \max(\tilde{f}_{ij}) \tag{4}$$

$$a_{ij2} = \min(\tilde{f}_{ij}) \tag{5}$$

$$b_{ij1} = \max(\tilde{g}_{ij}) \tag{6}$$

$$b_{ij2} = \min(\tilde{g}_{ij}) \tag{7}$$

These terms are used to determine the membership functions, which were chosen as follows:

$$\sigma_{ij1} = \frac{\tilde{f}_{ij}(x(t)) - a_{ij2}}{a_{ij1} - a_{ij2}} \qquad \xi_{ij1} = \frac{\tilde{g}_{ij}(x(t)) - b_{ij2}}{b_{ij1} - b_{ij2}}$$
$$\text{and} \tag{8}$$
$$\sigma_{ij2} = \frac{a_{ij1} - \tilde{f}_{ij}(x(t))}{a_{ij1} - a_{ij2}} \qquad \xi_{ij2} = \frac{b_{ij1} - \tilde{g}_{ij}(x(t))}{b_{ij1} - b_{ij2}}.$$

Finally, using these functions, the weight of each local model, α_i is calculated:

$$\alpha_i = \sigma_{ijp_f} \xi_{ijp_g} \tag{9}$$

The local controllers G_i, at Figure 5, are obtained by means of local models, which are linear. Worth comment that these local controllers were determined using the linear quadratic regulator (LQR), which is solved by linear matrix inequalities (LMI). The weight of each local model was determined considering Equations 8 and 9.

Given that the system presents two nonlinearities (electromagnetic forces in x and z directions), and that two actuators are necessary for each direction, since the electromagnetic actuator only exerts attraction forces, the required methodology had four local models. Additionally, the control was designed considering the first four vibration modes.

3. Results

The fuzzy control was analyzed for two situations, one considered only an impulsive load at disk one, and the other considered a mass unbalance at this disk.

Initially it is considered an impulsive force of 100 N applied at disk 1, while the rotor is at a rotational speed of 1600 rpm, which is slightly lower than the first critical speed for the rotor (1640 rpm). The local controllers were designed using the LQR, the global controller was achieved by the methodology presented in Section 3. Figure 6 shows the displacement for the analyzed systems.

The response of the controlled system shows that the controller reached the desired expectations, since the system response was decreased. In an interval of approximately 0.1s, the displacement in the x direction was reduced from 9.87×10^{-5} m to 2.95×10^{-5} m, which represents 70,1% of amplitude reduction, for z direction, the amplitude was decreased from 8.12×10^{-5} m to 3.86×10^{-5} m, resulting in 52.4% reduction.

Figure 7 shows the electromagnetic forces that was applied by the EMA to control the rotor system. It can be observed that higher force application occurs in the cycles closer to the impulse. After 0.05s of the impulse, the magnitude of the control force decreases to approximately 5% of its maximum, which for x direction was approximately 130 N and for z direction, the force reached the maximum of 230 N.

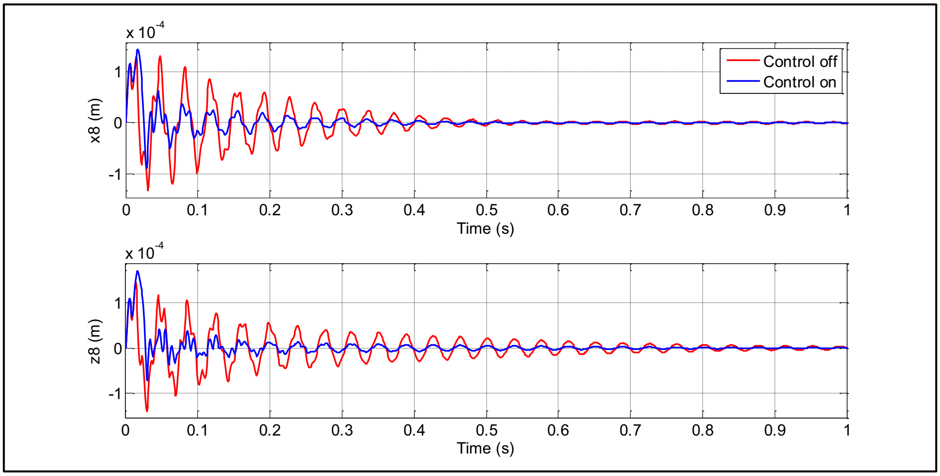

Figure 6. Displacement Response – impulsive case.

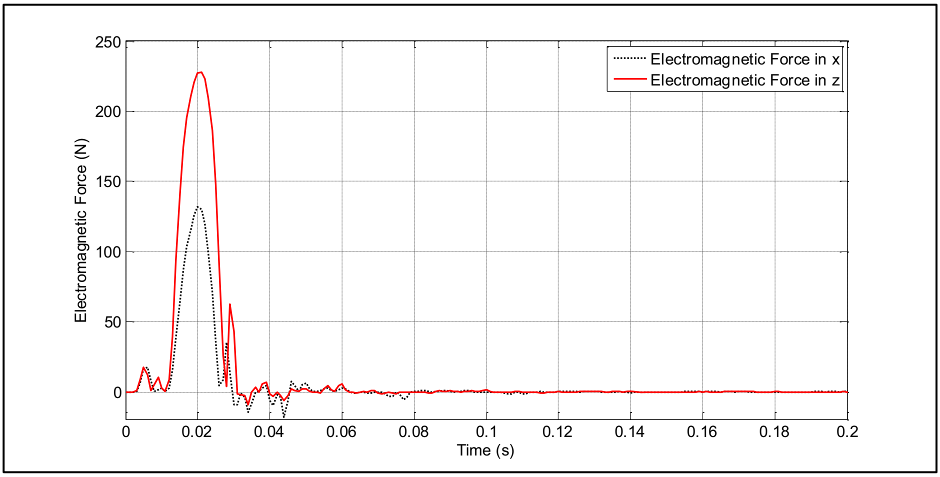

Figure 7. Electromagnetic Forces – impulsive case.

The second situation analyzed considered a mass unbalance of 2 x 10^{-4} kg.m at disk one, which started to actuate while the rotor was at 1600 rpm, at t=0. Figure 8 shows that the vibration was attenuated by the fuzzy control. In *x* direction the amplitude of was reduced from 1.66 x 10^{-4} m to 7.92 x 10^{-5} m, which represents 52.2% reduction, and for *z* direction the it was reduced from 2.99 x 10^{-4} m to 1.51 x 10^{-4} m, which is 49.5% of reduction.

The EMA forces are illustrated in Figure 9, it can be observed that the maximum actuator forces are approximately 80 N, and the system reaches a stabilization after 0.2s.

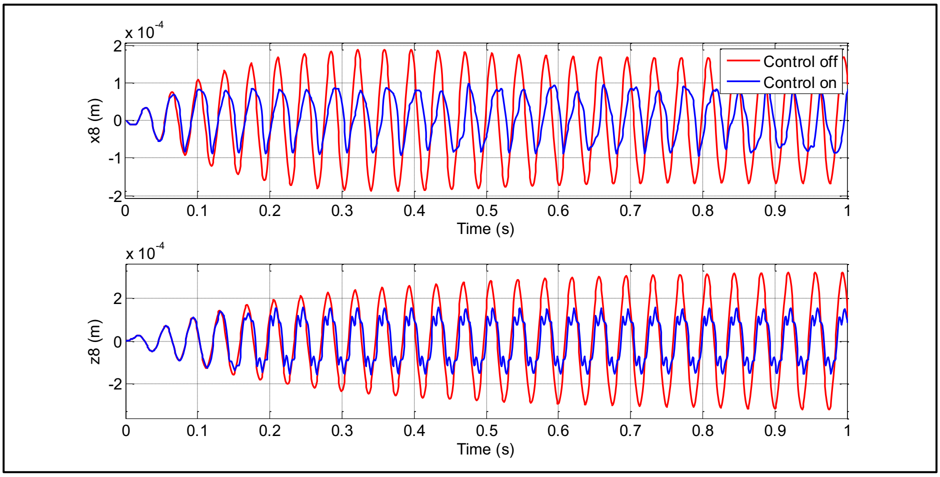

Figure 8. Displacement Response – mass unbalance.

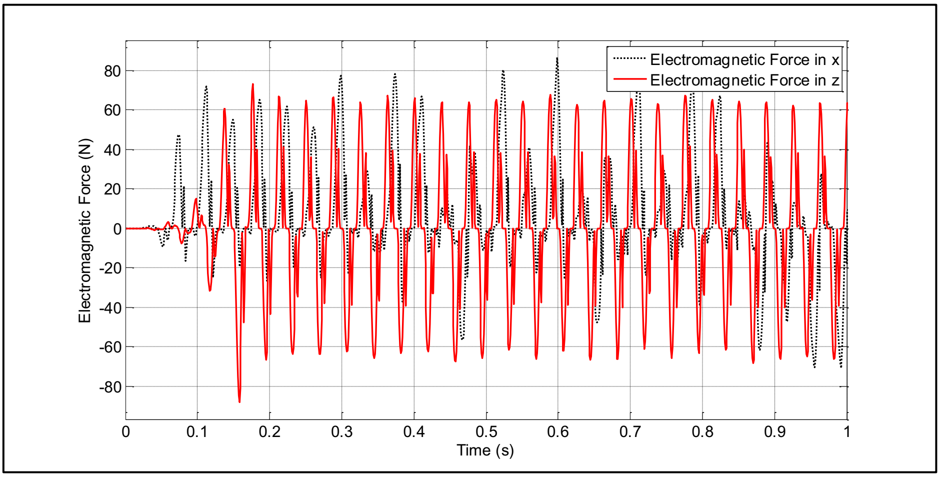

Figure 9. Electromagnetic Forces – mass unbalance.

4. Conclusion and Discussion

The results that were presented had shown the efficacy of the use of Fuzzy Logic to control rotational systems. The Takagi-Sugeno model, related to the parallel compensation, allowed the solution of the electromagnetic actuator nonlinearity by using local models. The LQR was used to solve these local models, and through it controlling the global system. Considering the results obtained by means of computational simulations, it is observed that the objective of the work in showing the efficacy of the control technique by means of Fuzzy Logic using non-linear electromagnetic actuators applied in the rotor system was achieved.

In future work we intend to improve the control of the system and simultaneously lower the EMA forces that are applied to the system, a way of doing that probably will rely on altering the membership function and to adapt the LQR controller aiming a higher efficiency control system. The proposed method can be validated in experimental test in a rotor test rig presented in [7].

Acknowledgement

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Indirect 3D Scanning of the Foot Plant - Comparison Between a Medium and Low-Cost Tools

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Abstract. The direct or indirect 3D scanning of the foot's plantar region can be used to manufacture customized insoles, orthosis and orthopedic shoes. The equipments that enable an efficient direct scanning are, in most cases, expensive and inaccessible to professionals. The inability to use such equipment, leads to recourse to indirect scanning with low-cost tools to generate the digital model. In this context, the aim of this study is to compare dimensionally the physical model with two virtual 3D models, one generated by a medium-cost equipment (MDX-40) and the other generated by a low-cost (Memento). To accomplish this goal a model in plaster of the plantar region of a healthy subject was made and later scanned by both methods. Five (5) regions or features of the plaster model were identified and measured. The dimensions were also virtually measured in a 3D CAD environment, in both scanned models. The methodology allowed to conclude that the 3D scanning made by MDX-40 presented a relative error of 0.72% compared to plaster model, while the Memento showed a relative error of 2.85%. In addition, the 3D scanning made by MDX-40 lasted 48 times longer than the Memento process. In view of the difference in cost and time for 3D scanning, the Memento can be considered more viable and interesting than the MDX-40, however, one study is necessary to evaluate the influence of the relative error in the quality of customized insoles.

Keywords. Photogrammetry, 3D scanning, custom insoles, foot plant

Introduction

Custom insoles, also known as foot orthoses, are orthopedic devices indicated as part of treatment to decrease the spine and lower limbs pain, rheumatoid arthritis, metatarsalgia, diabetic foot, among other sensorimotor problems that affect the feet. Such indica tion is due to better distribution of body mass on the plantar area, resulting in an alignment of the pelvis and spine [1].

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Currently, for making these insoles, foot experts use a scanning systems of plantar region to know about foot posture and the center of mass distribution. These data are sent to the CAD/CAM (Computer-aided Design/Manufacturing) systems for making the device suitable for the needs of the user.

An example of process for custom insole manufacturing, used by Ethnos company[2], can be seen in the scheme of Figure 1. The first step is the 3D scanning of the users foot to acquire a virtual model. In a specific software, the virtual model is used to develop a custom insole, whose manufacturing is performed by a Computerized Numerical Control (CNC) machine. At the end of the process a layer of a specific material is fixed on the surface of the insole for improving the comfort.

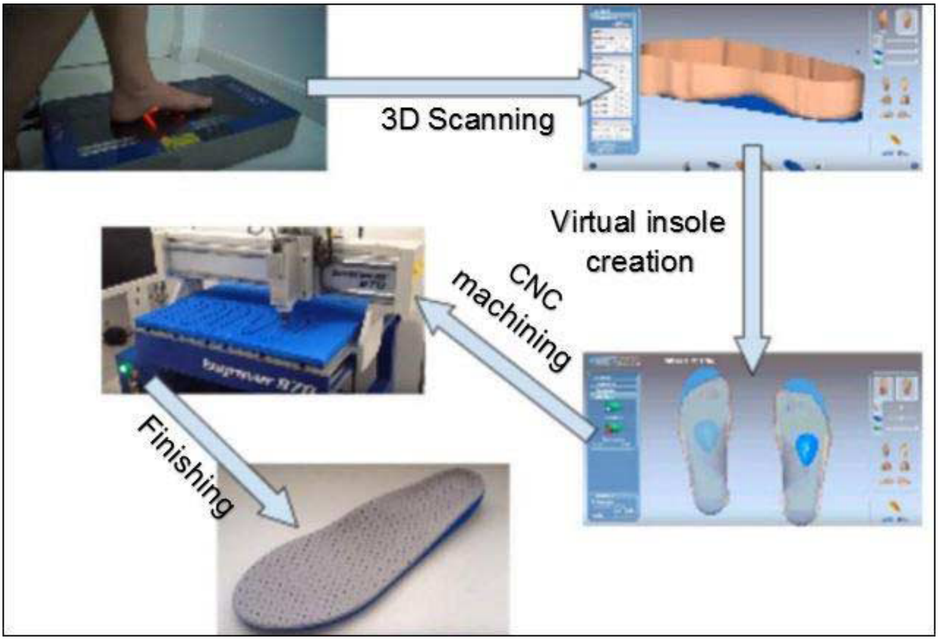

Figure1. Scheme of custom insole manufacturing process, Tailored Ethnos (2013).

Although there are benefits and proved efficacy associated with the scanning tools, 3D CAD programs and the use of digital systems for manufacturing, Dombroski et al. [2] reports the high cost of these technologies as a limiting factor for their application. Therefore, there is a research need to provide the use of these technological devices but to do so at a relatively low cost level.

In this context, this article consists of a dimensional analysis of the foot model generated by two indirect scanning[3] techniques, one with a low cost and another with a relative higher cost.

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[2]Ethnos: Brazilian company engaged in the making of substitutive prostheses of amputated limbs and corrective orthoses, tailor-made. It also offers manufacturing of insoles and baropodometry rating services. http://ethnos.com.br/.

[3]In the indirect method a mold of the anatomical region of interest is commonly made in plaster, and this is then scanned [3].In the direct method the scanning is performed directly in the region of interest.

1. Literature review

Researches using digital models of body segments demonstrate how such digital models can be useful for ergonomic analysis and the development of customized products and services. With the growing popularity of additive manufacturing, the ability to obtain and replicate faithfully the human body parts is promoting studies with this focus. Some examples of research applications in 3D scanning of body segments are described below.

In order to define a better method for the creation of chair seats for people with disabilities, Silva et al. [4] compared three scanning techniques - three-dimensional scanning with a fixed laser scanner, portable laser scanner and photo-based scanning (photogrammetry) using a conventional digital camera. They compared the digital models in 3D CAD environment that allows analysis of dimensional deviations of the surface. They concluded that the three scans methods are effective, however photogrammetry has lower dimensional accuracy, with an average error of up to 5 mm.

Camardella et al. [3] evaluated the accuracy of the plaster cast 3D scanning for orthodontics. They concluded that the digital model from the cast is faithful to the user anatomy, being an important option for the area.

For the development of an foot and ankle orthosis, Telfer et al.[5] performed direct scanning of the foot and reported the impossibility of positioning and manipulation the limb was a limiting factor.

More specifically in relation to the 3D model of the plant area, Pallari et al. [6] scanned directly the sole of the foot of seven people with rheumatoid arthritis for analysis and development of custom insoles manufactured with additive manufacturing. They used a portable laser scanner and, from the digital model generated, developed customized prototype for each individual.

Meneses et al. [7] emphasized that direct scanning has the advantage of speed and efficiency, however there is need for a static position of a member to prevent the inaccuracy of digital model. Thus, the authors stated that the indirect process turns out to be the most used. In this case they mentioned two forms of acquisition of foot anatomy, the use of phenolic foam or alginate to create the mold and the application of plaster to obtain the model.

This work intends to use the available resources in Prototyping and Tooling Group (NUFER) of UTFPR to conduct a comparative study between medium and low cost tools for indirect scanning of the plant foot area.

2. Materials and methods

This work was divided into 3 main topics: the cast and the model of the foot sole generation, the digital models and the dimensional evaluation.

To generate the cast of the foot sole, it was used alginate (200 grams) and then plaster (100 grams) was used to obtain the model. The virtual foot sole was obtained indirectly (from the plaster cast of the foot sole) by point-to-point scanning, using the Roland MDX-40 machine, and by photogrammetry, using images taken by the camera of the phone Sony Xperia SP C5303 and the software Memento.

According to the specifications provided by Roland, the scanning head course is 305 x 305 x 105 mm in the x, y and z axis, respectively. The scanning accuracy is variable and up to 0.04 mm. This machine has an approximate cost of US$ 8,000.00.

The software Memento is available for free from Autodesk® and uses photogrammetry principles to generate, the 3D digital model of the desired object from a set of digital images. According to the developer, some care must be taken to obtain a more accurate possible 3D model. For example, it is recommended to have a scale object to ensure the dimensional accuracy of the model, position other objects close to the subject for reference during the model generation, use an adequate lighting to provide a contrast between the part to be scanned and the environment.

To obtain the plaster model it was first selected a plastic container with dimensions compatible with the foot of the user chosen for the study. Then the cast was made plunging the region of interest in the mixture of alginate and water, until the curing of the material. Then, the cast was filled with plaster to obtain the model of the foot planar region. Figure 2 contains 3 images representing the steps described to obtain the plaster model.

Figure 2. Main steps to obtainthe plaster model.

. The photogrammetry was performed with the plaster model placed on a table with a stamped fabric, with a 20 mm reference cube, as shown in Figure 3. A set of 62 pictures from different angles to capture details of the model was taken. These images were exported to the Memento and after a few minutes the Autodesk server, which was responsible for processing the images, returned the three-dimensional virtual model. The virtual model was exported to the STL (STereoLithography) format to be subsequently measured in 3D CAD environment.

The same software Memento has been used to apply a scale factor, obtained based on the edge dimension of the cube of 20 mm, which was 1.9 mm in the virtual model delivered by server. Figure 4 shows the three-dimensional model generated by Memento after the application of scale.

The plaster model was also used for the point-to-point scanning process performed by Roland MDX-40. To achieve that, first the object is positioned in the machine table and the limits of scanning area is defined. The resolution and quality of the desired mesh was set, which, in this case, was 1.00 mm in the x axis and 1.00 mm in y axis, with a fine quality. The lower resolution of the machine is 0.04 mm, however, due to the size of the object, this scan would take a few days if this was used. Using the chosen precision the point-to-point scanning process took 26 hours to be complete. The point cloud generated by the program was exported to the STL format to be measured in the 3D CAD.

Figure 3. Plaster mold positioning on the table to generate the images.

Figure 4. Virtual Model generated by Memento.

Measurement of the plaster and virtual models: First, an analysis was made in order to identify possible features to be measured in all models (physical and digital). This analysis resulted in five distances: big toe length; length of second finger; width at the base of the fingers; width of the foot and distance from the heel until the tip of the big toe.

Every distance was measured three times and an arithmetical mean of the values found was calculated. The measurement of the plaster mold was made with a Mitutoyo calliper with 0.02 mm resolution, while the generated models by Memento and MDX-40 were done in CATIA 3D CAD program. Figure 5 shows an example of measurement of each model. Figures 6 (a) shows the measurement of the plaster model, (b) the model generated by software Memento and (c) the Roland MDX-40.

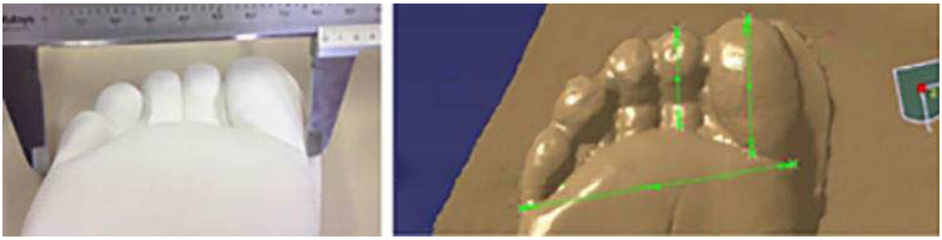

Figure 5. Measurement of models: (a) plaster model; (b) model generated by software Memento.

3. Results and discussion

From the 3D scans two surfaces were obtained for the dimensional analysis. Figure 6 shows the mesh generated by Memento (a), the mesh generated by MDX-40 (b) and the dimensional deviation analysis (c).

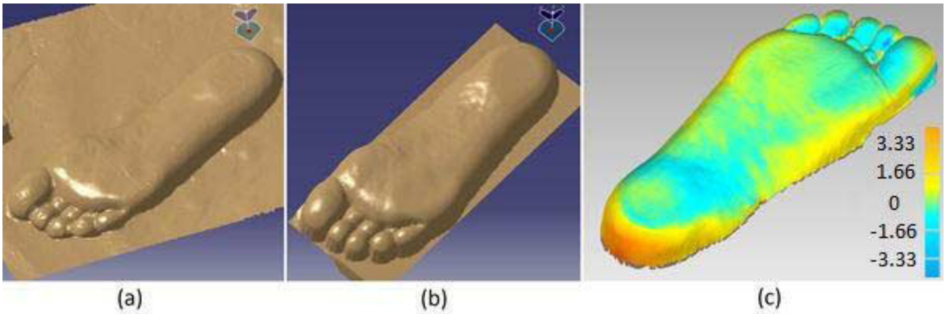

Figure 6. Generated surfaces: (a) by Memento; (b) by MDX-40 and (c) dimensional deviation analysis.

The dimensional deviation analysis, Figure 6 (c), is calculated by Geomagic 3D CAD program overlapping the surface generated by Memento over MDX-40 surface. The result is shown in the image by the color difference, represented by the color scale in milimeters shown in the image. This analysis indicates that the both scans showed similar topography of the plantar region of the foot. The surface generated by Memento presented more irregularities, however, by because of freedom of the scanning angle, this mesh provided details that the scanning needle of MDX-40 failed to capture, especially between the toes. Table 1 lists the dimensions of five features of the two digital models, as well as the relative errors of each case when compared to the measurements of the plaster model.

Comparing the dimensions and the relative error, it is possible to note that the point-to-point scanning showed lower relative errors when compared to scanning by photogrammetry.

One detail that drew attention was that the difference between the plaster model and the MDX-40 did not exceed 1 mm, which was the resolution chosen for the point-to-point scanning.

Stands out as a limiting factor for the measurement accuracy the fact that the model has an organic surface, with few details to be measured with good repeatability. To reduce the errors, each measurement was performed three times by the same operator, and then the arithmetic mean of these values was calculated.

Table 1. Dimensions and relative errors of each digital model.

Dimensions	Plaster model (mm)	Memento (mm)	Relative error Memento %	MDX-40 (mm)	Relative MDX-40 %
Toe length	39.68	40.80	2.82	39.3	-0.81
Second finger length	28.92	28.23	-2.39	28.51	-1.42
Width on the basis of fingers	82.26	83.48	1.48	82.16	-0.12
Width tip	85.86	89.62	4.38	85.14	-0.84
Distance from the heel to the tip of the big toe	225.62	232.82	3.19	226.59	0.43
Arithmetic average of the relative errors (module)			2.85		0.72

Although Memento showed higher relative errors, it would be possible to reapply the scale factor in the model until it became closer to the real value.

Regarding scanning time, MDX-40 took more than a day to scan the plaster cast, while with Memento, the virtual model was obtained in less than thirty minutes.

4. Conclusion

This study presented a comparison between two scanning technologies (photogrammetry and point-to-point) aiming to identify which is able to generate virtual models more accurately. Using the presented methodology it was possible to conclude that the scanning point-to-point using the MDX-40 had better dimensional accuracy and surface quality when compared to scanning done by photogrammetry. However, the 3D model generated by Memento presented more details and was around 48 times faster.

Overall, MDX-40 is interesting for scanning parts with small details, once they can be reached by the scanning needle (which has three degrees of freedom). On the other hand, Memento becomes feasible to objects with larger surfaces and / or in situations where a rapid scanning is desired.

For custom manufacturing insoles, it is believed that the 2.85% relative error presented by Memento could be compensated with the application of soft material on the surface. However, as the goal of scanning body segments is to increase dimensional accuracy and the generation of anatomically shaped products, this error could result in inaccurate monitoring of foot structures. The real impact of this result in the use of anatomical insoles needs to be analyzed in further studies, including user testing.

However, this study showed the potential of this low cost tool in the 3D scanning process for the development of customized products.

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Optimisation of Operational Parameters Based on Simulation Numerical Model of Hydrogen Fuel Cell Stack Used for Electric Car Drive

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Abstract. Hydrogen fuel cell stack is used as a rare and sophisticated power source in nowadays electric cars. Our team has built ultra-light energy-efficient vehicle for research purposes that uses hydrogen fuel cell stack as a power source and electric engines as sole drive of the car. The problem of optimizing the operating parameters of the hydrogen fuel cell stack was solved by numerical simulation studies conducted on a simulation model of the hydrogen fuel cell stack. The paper presents a numerical simulation model of hydrogen fuel cell stack system developed in Matlab Simulink and the results of simulation allow the selection and optimization of the control parameters adapted to the specific conditions of use. The model reflects the performance characteristics of the cell and allows the simulation work and control of hydrogen fuel cell stacks composed of hydrogen tank, control valves and controller, sensors, energy buffer system (supercondensers) etc. The model of electric power source based on hydrogen fuel cell stack was built as a module that can be used in the previously developed simulation models of electric vehicles.

Keywords. Hydrogen fuel cell stack,energy efficient car,numerical simulation model,electric car

Introduction

The need for modeling processes and phenomena occurring during the operation of technical objects is well known. Such modeling in the context of the need to optimize the characteristics of a technical object or the operating parameters is extremely important. Numerical models provide the ability to numerical optimization based on the this model [1]. In automotive engineering, such models are built for different purposes. For modeling the dynamics of electric vehicles many advanced computer environments are used. Noteworthy platform ADVISOR (Advanced Vehicle Simulator) [2] is written as a program in MATLAB-Simulink. Program in their libraries gives the opportunity to analyze several solutions of supply system, the propulsion system or body of the vehicle. Another platform running in MATLAB-Simulink program is PSAT (The Powertrain System Analysis Toolkit), that allows simulations of many predefined solutions in conventional vehicles, electrical and other [3]. Evolution of the PSAT platform is the Autonomy system [7] available on the

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platform LMS Imagine.Lab. In addition to these simulation environments in which models are abstract and which take into account the nature of the mechatronic drive system of the electric vehicle, there are a number of specialized programs designed to analyze the dynamics, using multibody formalism, like the program LS-Dyna, Adams, MotionSolve.

Simulation models for analysis and optimization of energy consumption should allow the execution of high-speed calculations. This is particularly important when optimizing which is based on these models requires multiple repetitive calculations. For experimental vehicles at the Institute of Machine Design at the Silesian University of Technology modular models have been developed [1,5] using the platform of MATLAB-Simulink. From the very beginning modular structure of simulation model was assumed. Such modular structure guarantees ability to qualitative change in the individual processing modules and use different types of models, depending on the degree of development of construction and the level of knowledge available about subsystems of vehicle and phenomena. The basic modules of the simulation model are shown in Figure 1. The model includes the following modules:

- Vehicle model
- Track model
- External conditions model
- Strategy
- Movement resistance model
- Results module

Particular sub modules also have module construction.

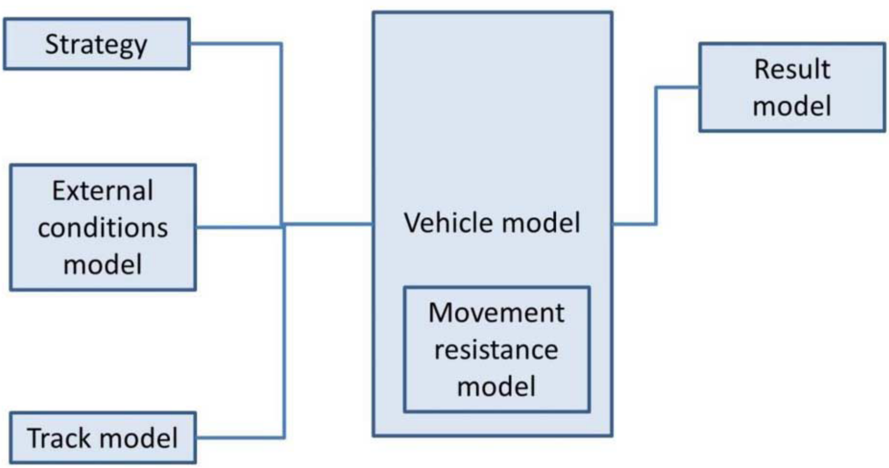

Figure 1. Framework of numerical simulation model for electric research vehicle – main modules [5].

In the case of research vehicles such design of the model allows easy replacement of the sub-module of the transmission system or the electric motor, eg. in the case of structural changes or to any other type of component. In addition, a simple theoretical models can be replaced by more accurate models after verification of individual systems for research positions. Complex computational models that require time-consuming calculations can be replaced with a faster and more accurate calculation models after optimizing fragments of the same model.

1. Simulation subject

The simulation model has been developed since 2013 from the beginning of the project of the first electric vehicle built for Shell Eco-matarhon. For the first vehicle the model allowed to predict with great accuracy the result of the race and plan strategy for driving during the race. For the second vehicle – Bytel - because of a completely different design and different parameters of driving at the race it was necessary to introduce a fairly significant changes to the model. These changes also coincided with the need to introduce a new power source - hydrogen fuel cell for the third vehicle – *Hydro*GENIUS.

1.1. Research vehicle HydroGENIUS

Energy consumption and energy modeling is particularly important in the case of energy-efficient vehicles. Smart Power team [6] of the Silesian University of Technology has been conducting research in the field of reducing the energy consumption of electric vehicles for several years. The result of this research are energy efficient experimental vehicles competing in the contest Shell Eco-marathon [7]. The team previously built vehicles competing in the three categories of racing Prototype Battery Electric [8] UrbanConcept Battery Electric and Hydrogen UrbanConcept [1]. These racing vehicles achieve very good results placing in the top ten results.

Since the beginning simulation models have been built for these vehicles so that at every stage of development it is possible to consciously decide about the parameters of the vehicle and investigate their impact on energy consumption. In the latest vehicle *Hydro*GENIUS [1] competing in the class UrbanConcept Hydrogen it was necessary to develop a simulation model of the vehicle with an additional cell hydrogen power module (Figure 2). This vehicle, unlike the previous two vehicles developed by the team of Smart Power, instead of lithium-ion battery has a hydrogen-powered fuel cell which produces electricity. The cell system operates in much more complex environment than the battery and the electrical power energy generation process is controlled by a complex control system, control valves and additional buffer supercapacitors. The complexity of this process and dependence of the efficiency of electricity production from the current parameters of the process resulted in the need to supplement the existing simulation models of the system module with a fuel cell powered by hydrogen.

1.2. The hydrogen fuel cell stack

The fuel cell stack used in the car is H-1000XP, made by Horizon Fuel Cell Technologies [9]. The instantaneous peak power can reach 1200 W and the nominal power of the fuel cell is 1000 W. The hydrogen fuel cell is supplied by 99% pure hydrogen at a constant pressure of 0.5 bar. The oxygen required for the reaction is drawn from the atmospheric air. In order to increase the airflow through the fuel cell stack, the cell is equipped with fans with variable speed control. The characteristics of the fuel cell stack and the hydrogen consumption is shown in the Figure 3. The characteristics are given in technical documentation of the fuel cell [9] and then transferred to the Simulink MATLAB® model.

Figure 2. Research vehicle *Hydro*GENUS.

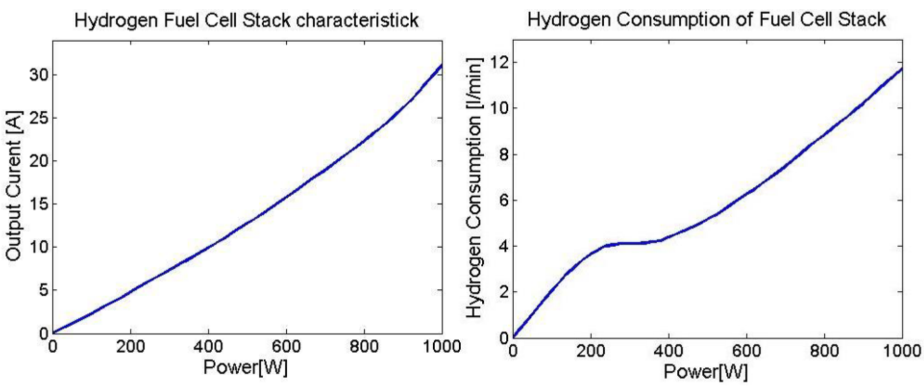

Figure 3. The characteristics of the hydrogen fuel cell stack(left) and hydrogen consumption(right)[9].

Efficiency of the hydrogen fuel cell stack varies, depending on the power of the cell. Hydrogen consumption increases with the increase of fuel cell stack power, however it is not a linear correlation. The efficiency of the fuel cell stack is the key for vehicle hydrogen consumption and is critical for its driving range. The Figure4 shows the efficiency of the hydrogen fuel cell stack depending on the power. It has been calculated based on the hydrogen consumption. The maximum efficiency is 54.7 % for the power 524 W. The efficiency for the values lower and higher than 524 W is much lower, especially for values from the range 0 - 200 W. The efficiency for the nominal power 1000 W is 47.9 %. It has been calculated in MATLAB®, according to the hydrogen conspumption shown in Figure 3 and the energy energy contained in hydrogen (1l/min= 178 W).

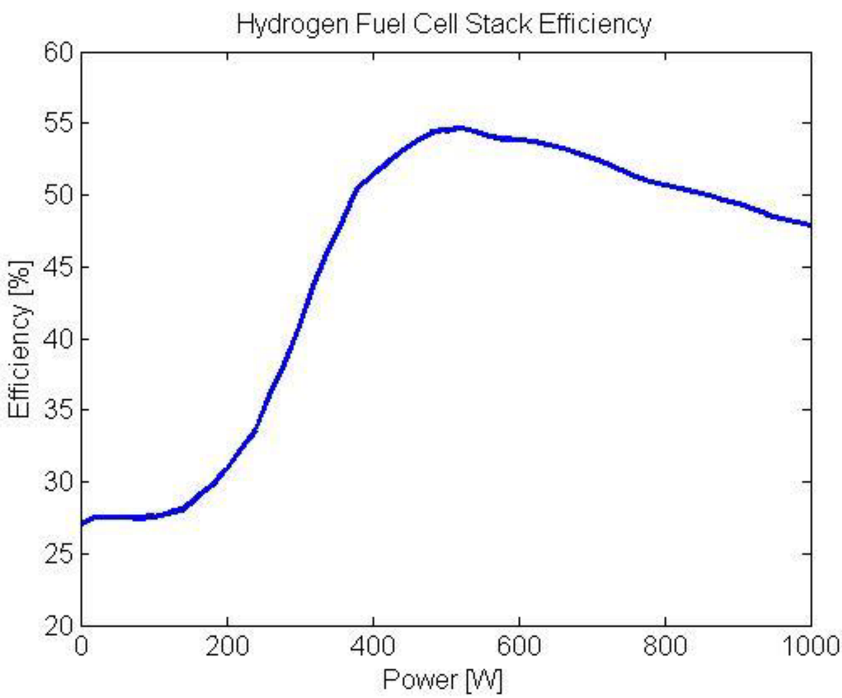

Figure 4. The hydrogen fuel cell stack efficiency.

2. The numerical model

The control of hydrogen fuel cell stack and selection of its working parameters is a complex problem. It is a problem of optimal control. The aim is to get the required power by minimal hydrogen consumption. Because the system is complex and many parameters are involved, it has been decided to build a numerical model of the hydrogen power cell with the motor.

2.1. Construction of the model

The model has been prepared in Simulink package of Matlab application. It consists of four main blocks: fuel cell stack block, engine block, capacitor block and the control block. Additionally, two other blocks have been used in the model: the output (result) block and the input (requied torque) block. To create the fuel cell stack block the characteristics have been used, without going into details how the cell works. It simplifies the model and is detailed enough for proper modeling of hydrogen fuel cell stack. The capacitor block is responsible for simulating supercapacitors battery installed in the vehicle, primarily for simulation of its charging and discharging. The engine block is a block responsible for the power demand of the system. Theblocks of the capacitor and the engine have been duplicated for proper modeling of two main control modes. The control block is responsible for the optimal control of the fuel cell stack. Currently, the block limits the maximum power of the fuel cell stack. All simulations have been performed for the fixed step size of 0.1 s. The design of the numerical model has been shown in Figure 5.

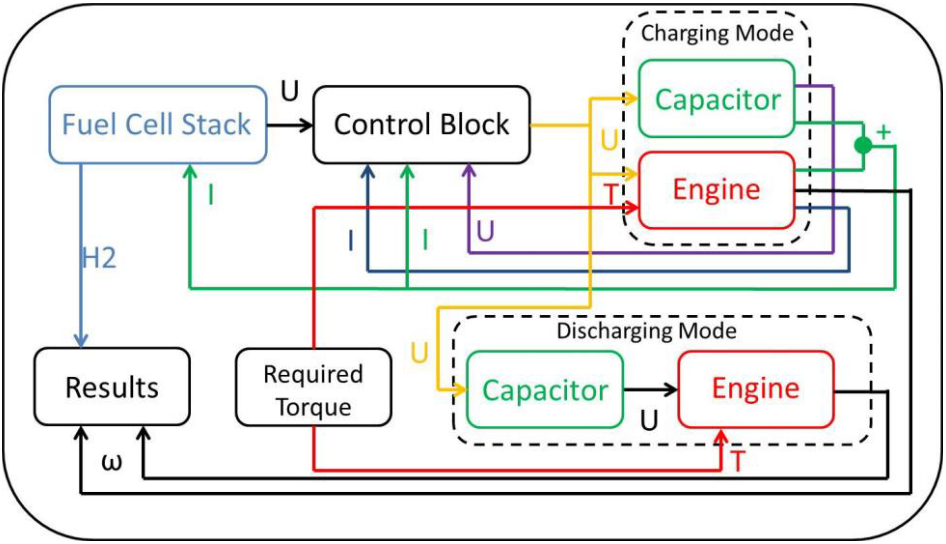

Figure 5. The numerical model diagram.

2.2. The modularity of the model

The input for the model is the required motor torque. The required torque can be saved as a constant waveform or the output of other numerical model. The model output is a instantaneous motor rotary speed and the hydrogen consumption. Through such solutions, the model is a separate system. However, it is possible to integrate the system with existing numerical models of a car and to integrate them into one complex system. With the integrated model, there is a possibility to optimize both working parameters of the hydrogen fuel cell stack and the moments of acceleration on the track. This allows more global optimization and helps to estimate the hydrogen consumption precisely.

3. The fuel cell stack control strategy

The control strategy of the fuel cell stack should be optimized. In this case, the control should provide the required amount of energy with a low amount of consumed hydrogen at the same time. Therefore, the fuel cell stack should work with realatively high efficiency. If high efficiency is not possible to achieve, the fuel cell stack should work with minimum power, so as to ensure the minimum consumption of hydrogen. In practice, the control of the fuel cell stack is possible to realize only by limiting the maximum power of the hydrogen cell or by reducing the supplied amount of hydrogen and air. The control, in this case, is a smooth change of this parameter. By temporarily reducing the maximum power of the fuel cell stack to the minimum, necessary for the functioning of the cells, it is possible to control the launch time of the fuel cell stack. Because of the low efficiency of the fuel cell stacks for the low power, the control strategy should provide using the hydrogen fuel cell stack only for high power. Therefore, for a low energy request, more benefit is when the fuel cell stack works intermittently with higher power and higher efficiency, than continuously with low power and efficiency. In case when the energy consumption is low, the energy should come only from the supercapacitors which should be periodically charged.

3.1. The route and the energy requirements for the vehicle

The race track is 10 loops, each 1.6 km. Each lap begins and ends by stopping the vehicle. It is necessary because of charging the supercapacitors battery and the rules of the competition. The rules force us to stop the car after each loop. It works as a simulation of the urban traffic. The maximum time for the whole route is 39 minutes. For the presentation purpose predetermined simple velocity profile for each lap was assumed. The required torque has been calculated in MATLAB®, based on the equations of the dynamics of material points and the known movement resistance of the vehicle for the velocity profile. The velocity profile and the the required torque profile for one loop have been shown in the Figure 6.

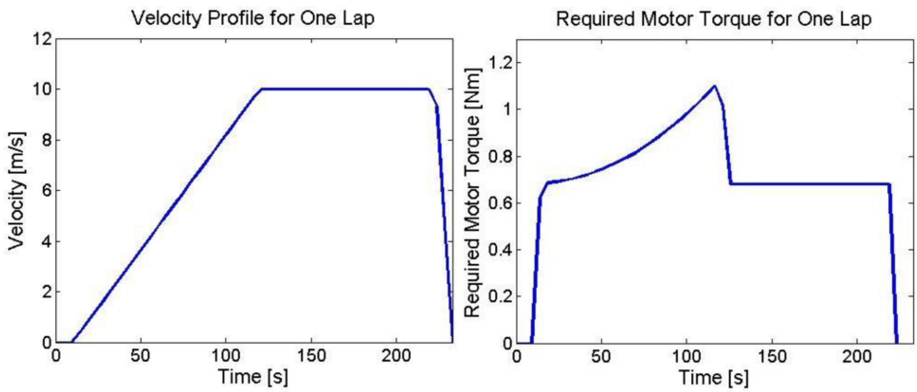

Figure 6. The velociy profile and the requied torque for one lap.

3.2. The control strategy and its realization

The control strategy of the fuel cell stack assumes, that the effort should be made to maximize the fuel cell efficiency. The work in the area of low efficiency should be avoided. For the cell used in the vehicle a low level of efficiency corresponds to a range of 0 - 500 W. Maximizing efficiency of the hydrogen cells allows producing the same amount of energy at a lower hydrogen consumption by the fuel cell stack. To control the operation of the cell, the maximum power of the cell is limited. In real conditions, it is possible to achieve this by reducing the amount of hydrogen and air delivered to the cell. During the model preparation, the main focus was put on the limitation of the power, skipping the setting of the solenoid valves.

To store the energy, a battery of supercapacitors has been used. If the level of energy stored in supercapacitors is high enough, the maximum power of the cell is limited to the minimum, necessary to sustain the operation of the hydrogen fuel cell stack. Due to its construction, the cell should not be completely off during the race. In this case, the energy supplied to the engine is delivered by supercapacitor. If the battery level is too low, the cell operates with a power sufficient to charge the supercapacitors slowly and to keep the engine running. The minimum power of the cell in this case is 500 W and it corresponds to the beginning of the area of high efficiency of the cell.

Regulation pattern of the cell operation can be represented as follows. If the voltage on the supercapacitors battery is equal or greater than U_{max}, the power of the cell is reduced to the power necessary to sustain its operations. For the voltage on the supercapacitors battery lower than U_{min}, the supercapacitors are charging. For voltage range between U_{max} and U_{min} the cell continues the last operation (charging or discharging the battery of supercapacitors). If the output power of the hydrogen fuel cell is less than 500 W, the maximum power of the cell is reduced to the minimum, necessary to sustain the cell operations. While charging, the maximum power of the cell is determined as the power consumed by the engine plus the value of A. The control is done periodically at a time interval T.

4. Optimization

The main goal of optimization is the selection of control parameters of the cell, such as: U_{max}, U_{min}, A and T. The parameters U_{max} and U_{min}, are higher and lower voltage limits for operation of the supercapacitors battery. For the voltage of the supercapacitors equals or is greater than U_{max} the supercapacitors are discharging. The fuel cell stack works only for the power necessary for its operation. When the voltage of supercapacitors is equal or lower then U_{min}, the supercapacitors are charging. The maximal power for the fuel cell stack is the motor power increased by the value of the parameter A. The control is done periodically at a time interval T. In addition, the subject of the optimization are the parameters related to battery of supercapacitors, such as their capacity C and resistance R. This optimization has been performed using a genetic algorithm method using MATLAB® and Global Optimization Toolbox. The model was developed in Simulink Toolbox in MATLAB® according to the diagram shown in Figure 5. The optimization has been carried out for the full 10 laps. The simulation time has been set as a permanent value of 2330 s. The parameters should be chosen to minimize the hydrogen consumption (H) by the fuel cell stack while maintaining other requirements. The objective function has been shown in equation (1).

$$U(q) = H^2 + \delta \tag{1}$$

In equation (1) δ is a penalty function. This function takes the value 1E7, if one of the additional criteria is not met. These are criteria such as: distance run over by the vehicle is equal or greater than the route of the race; there has been no drop in voltage on the battery supercapacitors below 31 V sosimulation must be feasible (for some specific parameters it is not possible to calculate the model). The optimized parameters have been given as vectors of possible value. Optimization parameters were selected according to the recommendations in the literature [10].

5. Results

The simulation has been performed 5 times. Several optimizations allow to make a general conclusions about the final values of the optimized parameters and to increase the chances of finding the lower value of objective function. The results of the simulations have been shown in Table 1.

Table 1. The Optimization Results.

Attempt	U_{min}[V]	U_{max}[V]	A[W]	T[s]	C[C]	R[Ω]	Final Fitnees function value
1	32.7	41.1	190	4.7	1	4.5	62854
2	33.9	41.7	190	2.0	1	5	62855
3	33.5	39.7	180	1.6	1	4.5	62853
4	36	41.7	210	4.7	1	4.5	62828
5	33.5	41.4	190	4.5	1.5	1.5	62859

The results allow to make the general conclusions about some parameters, especially about the capacity of the supercapacitors battery. The final result for all the simulations shows that the capacity of the supercapacitors battery should be low. It is the most important parameter. The result for capacity of 12 C is 1.7% worse then for capacity of 1 C. The U_{min} should be low and U_{max} should be high. The A parameter should be about 200 W. The best result has been obtained for attempt 4. The result for the simulation with the control system is 0.16% better than for the same parameters but without control system (maximal power of the fuel cell stack is constant and equals 1000 W).

6. Conclusions

Optimisation based on numerical simulation model has not provided clear results. Determination of the level of key parameter - capacitance is surprisingly low. The results of calculations for a much higher battery capacity of supercapacitors are substantially similar to the optimal results and indicate that the capacity has not so significant influence on the hydrogen consumption. In addition, calculations carried out without a pre-planned strategy - for the nominal operating conditions of the cell also give a result very similar to the optimum. The reason is the specific test conditions and repeatable performance of lap race, which do not give the possibility to benefit from both the control and optimised features of the system. It is necessary to carry out further calculations for the race conditions in search for a different control algorithm. Further development of research can be seen in developing a profile lap leading to simulation of actual driving urban vehicle. It is possible to achieve by changing the parameter speed, leaving other conditions as acceleration and deceleration set to similar values and the introduction of high variety of established parameters. This will allow for the introduction of operating conditions much closer to the conditions of urban driving which together with the search for a different control algorithm may lead to finding the optimal control algorithm and the optimum parameters of the power supply with hydrogen fuel cell stack in conditions of urban driving.

Acknowledgement

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Design for Autonomy: An Integrated Product Development Tool for Reengineering of Complex Products for the Brazilian Space Sector

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Abstract. This paper presents the integrated product development tool Design for Autonomy for reengineering of foreign complex products. Design for Autonomy is a new member of the Design for X family, which aims at integrating the requirements from the X area, in this case autonomy, into the conceptual phase of the product development process. This tool regards to decision making activities and their outcomes: decisions about the interrelations with the design of products. The objective of Design for Autonomy is to assure that the product can be designed, produced and operated in Brazil for a defined period of time at a minimum risk of being dependent on export bans or unavailability of components. This can be accomplished by the Design for Autonomy model comprising four steps: (1) An analysis to identify critical elements and means for achieving their technological domain; (2) Preparation of nationalization; (3) Reverse engineering of the original product in order to obtain the technological know-how; and (4) Forward engineering including the adaptation for the new environment in Brazil, stimulating improvements and added value. In a pilot project, the Design for Autonomy tool is being successfully applied to the development of a Brazilian thrust vector control system, a subsystem used for attitude control of satellite launch vehicles. The technology originates from the German Aerospace Center (DLR) and is transferred to the Brazilian Institute of Aeronautics and Space (DCTA/IAE).

Keywords. Integrated product development, Design for X, Design for Autonomy

Introduction

Brazil has a high technological dependence of space technologies, compared to other space fairing nations like India, Japan or China who have high level of priority for full independence of technologies. In the past, the Chinese and Indian space programs have been compromised by international markets for space technologies and thus, have built up strong domestic capacities [1].

Another example is Japan, which only undertakes a space mission if it can be assured that Japan is able to launch its spacecraft. Japanese governmental satellites have never been launched by foreign launch service providers [1]. History shows that,

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besides Germany, all countries looking for rocket technology used technology transfer for achieving national domain typically with the following four steps: (1) Procurement/proliferation; (2) Reproduction under license; (3) Performance advancements; and (4) Own development [2]. Technology transfer strongly depends on the culture, organization, politics, human infrastructure, and availability of components that are dominant inside the new environment. It is a common faulty assumption that a system, technology or a process works without major problems in a different context or in a new environment. Transferees are obliged to match the functions and assimilate, adapt and improve upon the original technology [3]. This paper introduces an integrated product development tool nominated Design for Autonomy to nationalize strategic technologies applied, embedded or implemented within a product.

1. Design for Autonomy

The Design for Autonomy tool is a new member of the DFX family, developed on basis of the DFX shell [4]. The term *autonomy* can be rendered as self-rule or self-determination and is used in this context as freedom from external control or influence. Design for Autonomy refers to the processes necessary for the successful nationalization of strategic technologies applied, embedded or implemented within a product which is realized via reengineering. The model of Design for Autonomy is depicted in Figure 1. The first activity of the product development process, the 1st step, is the modeling of the product for further analysis including the identification of critical elements of the product. The nationalization of the product is being prepared in the 2nd step. Having a prepared product/technology as well as a prepared environment for nationalization, reengineering is carried out in order to obtain a national product (3rd and 4th step).

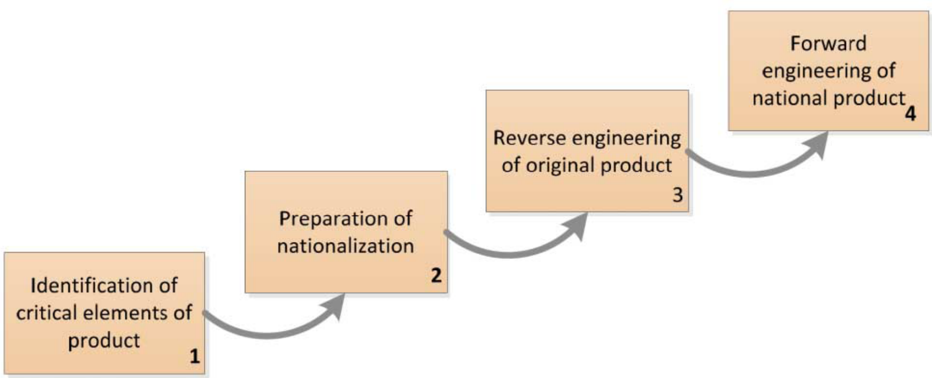

Figure 1. Model of Design for Autonomy consisting of four steps.

The process of reengineering is illustrated in Figure 2 and initiates with reverse engineering, an analysis of the original product that includes design recovery originating from the implementation phase and the design phase, restructuring the requirements of the system (data-to-data) and the design (graphical and functional).

The second part of the reengineering process, the forward engineering, continues with the definition of new and modified requirements. New national designs are created in order to achieve the development of a national product. The term *forward* is necessary to implement in order to distinguish this process from reverse engineering.

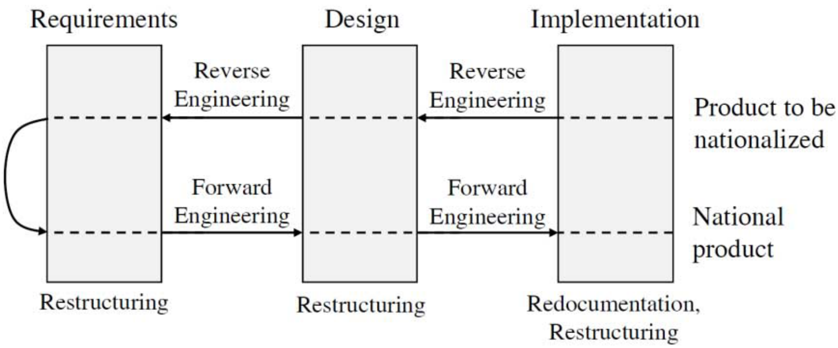

Figure 2. Relationship between the terms of Forward-, Reverse- and Reengineering represented by life-cycle phases, after Chikofsky and Cross [5].

Design for Autonomy is part of a comprehensive systematic strategy for nationalization of foreign technologies which is called Technology Nationalization Framework (TNF) [6]. This framework comprises the identification of strategic technologies in Brazil and gives support for the decision making process for their nationalization. An evaluation of feasibility for development of national domain and subsequently its coordination and cooperation helps to stimulate the best use of resources and competencies available in Brazil. Intellectual property related questions are part of TNF prior to the application of the Design for Autonomy tool.

In the following, the processes of the four steps of Design for Autonomy are presented in detail, using a function modeling methodology based on IDEF0. Each function or activity of the respective step is placed in a box, identified with a number at the bottom right. Inputs are represented by arrows entering the left side, outputs by arrows exiting the right side. Control/management is represented by arrows entering the top of the box and mechanisms/processes by arrows entering from the bottom of the box.

1.1. The 1st step - Identification of critical elements

The activity of the 1st step, the identification of critical elements, is illustrated in Figure 3. This first step is required in order to analyze the product to be nationalized, to adequately represent the product for further design decisions, and to collect and categorize product information. In case of identification of high critical elements, action lists are generated in order to obtain technological domain. Not identified critical elements may hinder or impede the product development process or may result in project delays or excessive cost. This activity is the initial step of the Design for Autonomy tool, breaking down a complex product into manageable elements which are being identified.

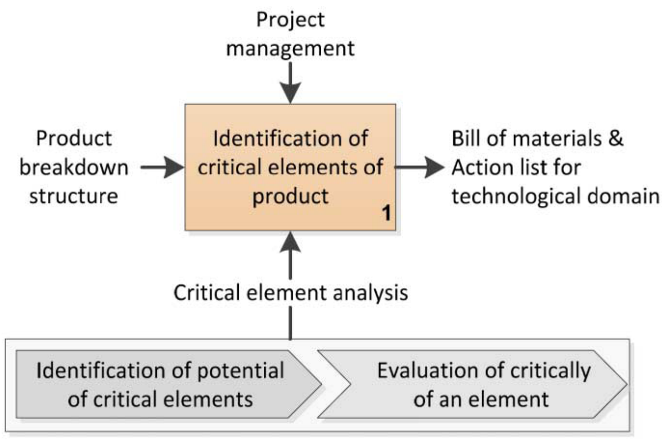

Figure 3. 1st step of Design for Autonomy: Identification of critical elements of product.

1.1.1. Modeling for product analysis

According to Huang et al. [4], the product modeling can be characterized into three general categories of product information, namely, composition, configuration, and characteristics. The composition of what the product consists of is allocated into the Product Breakdown Structure (PBS), a technical tree which is a structured representation of all various elements of a system [7]. A PBS is a hierarchical structure of the complete set of physical systems and subsystems including operational system, training system, development support, production support and so on, which identifies the configuration items [8]. It hierarchically details the elements, or physical components of the respective product beginning with the final product at the top of the hierarchy, breaking down a complex product into manageable elements. The PBS also includes non-exhaustively the configuration of the product, defining the relations between the elements.

Further information of the configuration and the key characteristics of the elements for the Design for Autonomy tool are included in the bill of materials, represented in Table 1. Besides the standard entries (hierarchical level, part number (PN), revision, description, quantity and unit), the criticality of the elements and a make, buy or make and buy decision is added.

Table 1. Sample for bill of materials.

Level					PN / Specification	Rev.	Description	QTY	Unit	Criticality of element	Make, buy
0	1	2	3	4							

1.1.2. Mechanism of identification of critically of elements

In a first stage, it is assessed if the respective element has a potential to be critical for the development of a national product. Therefore, the questionnaire is applied to define: (A) if the element is relevant for the product, and (B) if this elements requires development of technology. A potentially critical element will be diagnosed if the respective element obtains at least one 'yes' in both categories (A) and (B). This first evaluation is based on the TRA Deskbook [9] and was adapted by the Brazilian Center for Strategic Studies and Management in Science, Technology and Innovation (CGEE) [10].

In a second stage, the criticality of an element is determined, which is executed for those elements that are marked as potentially critical elements. The flow chart for evaluation is depicted in Figure 4, which is based on the InsightTec tool from CGEE [10]. For the input, the following information of an element to be evaluated is required: manufacturer, manufacturing country, majority shareholder of manufacturing company, and export restrictions from

1. respective national institutions (e.g. from Export Administration Regulations (EAR), International Traffic in Arms Regulations (ITAR) and Treasury Department's Office of Foreign Assets Control (OFAC) for US goods or Federal Office for Economic Affairs and Export Control (BAFA) for German goods), and
2. multilateral export control regimes (e.g. Missile Technology Control Regime (MTCR) [11] or the European Council (EC) Regulation No. 428/2009 [12]).

Four different categories of criticality can be obtained from the evaluation which are defined as:

- Non-critical element: No short or long term restrictions for acquisition or production of element in Brazil; sufficient alternatives available.
- Low-critical element: Long term availability for a specific element with limited acquisition resources in Brazil or unlimited acquisition resources out of Brazil assured.
- Medium-critical element: No long term availability assured and uncertainty of future acquisition or unlimited acquisition resources for a restricted element in foreign country. Furthermore, an element on critical project pass may be classified as medium-critical element.
- High-critical element: Restricted access or difficulties in acquisition and availability for identified element.

The availability of elements is characterized by three different stages, namely:

1. Independence - The required technology is/was developed and the element is produced in Brazil,
2. Non-dependence - Brazil has free, unrestricted access to the element and its technology, and
3. Dependence - Brazil has restricted access for acquisition of the element.

Annotation: The definitions used herein are adapted from the EC-ESA-EDA workshops on Critical Space Technologies for European Strategic Non-Dependence [13].

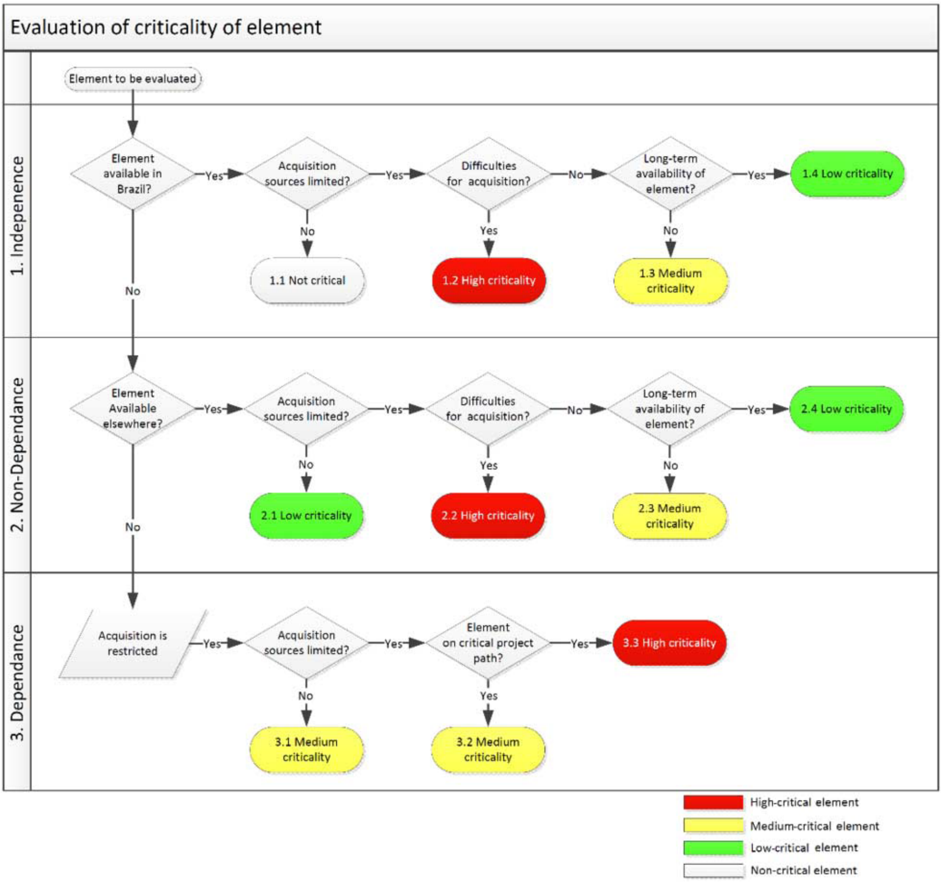

Figure 4. Determination of critically of elements, after ESA [14] and CGEE [10].

1.2. The 2nd step - Preparation of nationalization

The acquired data from the first step is necessary to prepare the nationalization. The second step, depicted in Figure 5, involves specific preparations for the product itself and preparation of the setting in order to generate an adequate and prepared environment for the nationalization. The product specific preparation provides insight into the national and international industry for the product and its elements, including the possible critical elements. Furthermore, a research of possible patents avoids the violation of international laws and the national and international research review gives an overview of the state-of-the-art. The preparation of the product setting includes the creation of an organizational structure for the Product Development Process (PDP) and the modification and adaptation of the necessary infrastructure and training. According to Andreasen and Hein [15], development projects require a separate organization since a range of activities does not fit into the existing pattern of the basic (external) organization. An *internal* organization is made up of work, project management and executive elements, whereas the *external* project organization acts as technical reference and supplier.

The preparation of nationalization is a continuous process that not necessarily has to be concluded before initiating the next steps. Efforts especially for the product specific preparation and the adaption of the infrastructure should be ongoing until the end of the product development to ensure the conservation of the *status quo* of a prepared environment.

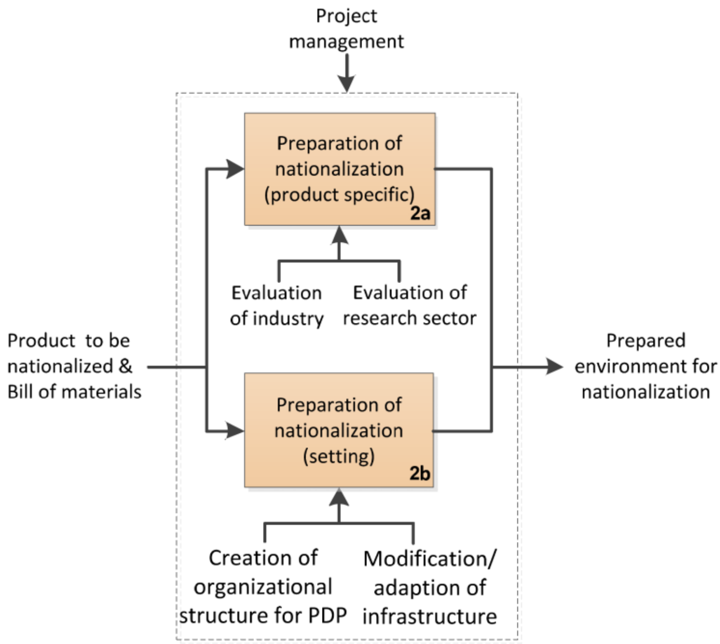

Figure 5. 2nd step of Design for Autonomy: Preparation for nationalization.

1.3. The 3rd step - Reverse engineering of original product

Reverse engineering of the original product, the first activity of reengineering depicted in Figure 6, aims to analyze and examine the product in order to identify its components and their interrelationships and to obtain the know-how and know-why. This knowledge is necessary in order to continue reengineering with the second activity, forward engineering to redesign a national product.

The activity of reverse engineering of the original product includes four tasks:

1. Procurement - The original product or at least a large part of it has to be acquired and imported from the transferor according to the bi-national contracts.
2. Assembly and integration - The original product has to be assembled and integrated in national laboratories with the adequate equipment and infrastructure.
3. Functional testing - Functional testing, if possible with technical staff and/or support from transferor, has to be accomplished in order to train the team and assure save handling and use, and to understand form and functionality of components and their interrelationships.
4. System identification and modeling - This task is case specific and depends on the product to be reengineered.

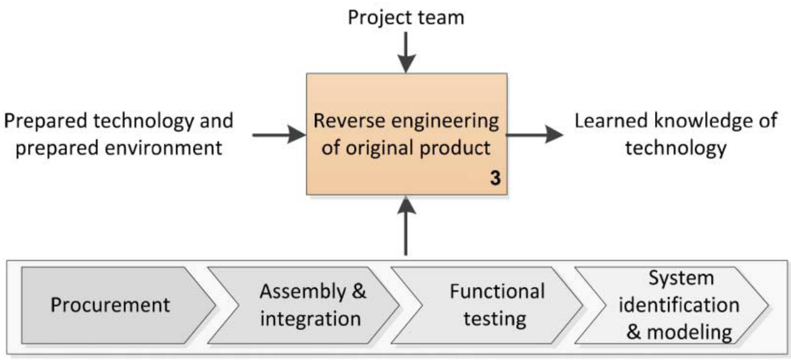

Figure 6. 3rd step of Design for Autonomy: Reverse engineering of original technology.

The reverse engineering has to be documented adequately in order to facilitate the forward engineering of a national product.

As an example for the reverse engineering, in Figure 7 the engineering model of the actuation system for the thrust vector control system at the transferor is depicted and in Figure 8 the national reverse engineered model. Based on the lessons learned from the transferor, the development of Brazilian engineering model prevented possible defects and shortened the development time, saved money and brought improvements upon the original model. This task revealed characteristics of the actuator like functional principles, dimensioning and effective areas of piston. The gained knowledge brought ideas for possible weight savings and performance gains.

Figure 7. Engineering model of actuation system at transferor.

Figure 8. Reverse engineered model of actuation system in Brazil.

1.4. The 4th step - Forward engineering of national product

The second activity of reengineering is forward engineering, depicted in Figure 9, using the gained knowledge from the reverse engineering activity. This step leads to the development of a product with national domain, reducing the risk of being dependent on export bans or unavailability of components. Furthermore, the knowledge of the original technology and the identification of its strengths and weaknesses give the opportunity for product enhancements, leading to innovation and added value.

The reverse engineering from the 3rd step brought knowledge of the design and requirements of the original technology. For the development of a national product, the original requirements get restructured, thus changed, modified or maintained and a new specification is obtained. With this new specification the designs get reviewed and if necessary changed or modified for the national product. The redocumentation assures a consistent technical documentation of the national product. Therefore, the available documentation of the transferor is reviewed, adapted, changed or modified and converted to the national layout, norms and standards.

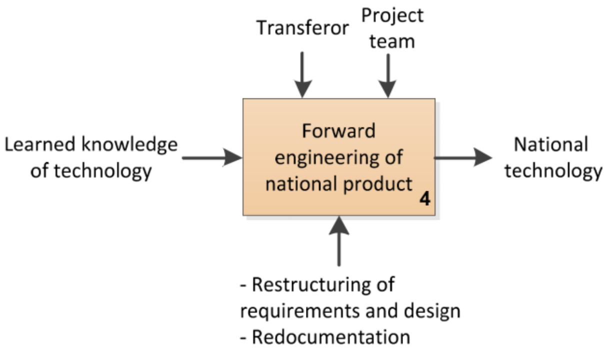

Figure 9. 4th step of Design for Autonomy: Adaptation for new environment.

The reverse engineering of the acquired actuator from the technology transferor together with the obtained knowledge from the actuators purchased for different applications and available literature for actuation systems lead to the forward engineering of Brazilian actuator engineering and qualification models, as illustrated in Figure 10.

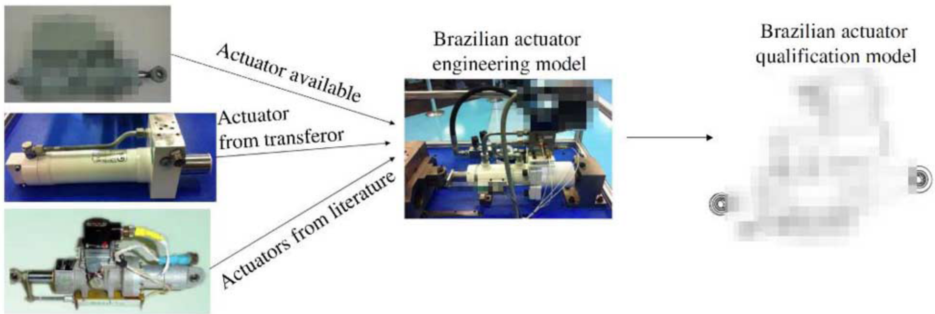

Figure 10. Flow of knowledge for forward engineering of Brazilian actuator engineering and qualification models.

2. Discussion

Like any manufactured product, the Design for Autonomy tool is set to be improved. In the pilot project for the development of a Brazilian Thrust Vector Control system, a right first time could be accomplished so far. Feasibility and the right focus of attention could be demonstrated by a balance between functionality and operability. However, validation is not a step that can be skipped and the tool has to be tested on a number of case studies for validation purposes. Design for Autonomy was being developed with the focus on the space sector in Brazil. Certainly, this tool and its processes may be adapted and adopted to other sectors / production industries in Brazil.

3. Conclusion

The integrated product development tool Design for Autonomy was introduced in this paper as part of the Technology Nationalization Framework for nationalization through reengineering of foreign high technology products. The application of Design for Autonomy fosters innovation and competitiveness in Brazil and ensures non-dependence of strategic technologies and products. Design for Autonomy is a balance between completely domestic/national development with intrinsically high cost, lead time and risk, and blind implementation of reverse engineering with risk of failure, more expensive solutions and/or higher vulnerability to embargoes. It includes product analysis of critical elements in order to not enter into a fatal spiral of total nationalization, where 100% of product has to be national. It represents a balanced development of reverse engineering that provides observations beyond those perceived by the original designer, creating an innovative scenario for straight forward engineering in order to prevent errors, save time and money and add value to the new national product. Design for Autonomy is a decision and design supporting tool that copes with high complexity and generates alternative views for a robust national design. The Design for Autonomy tool was successfully developed and applied within the Brazilian space sector, however, may be adapted and adopted to other sectors / production industries in Brazil.

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Systems Integration in the Lean Manufacturing Systems Value Chain to Meet Industry 4.0 Requirements

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Abstract. In the last two decades, technological and managerial changes are helping industrial organizations address the growing need to become more competitive, reducing production costs and delivering products that meet quality standards with higher performance. Two factors play a major role in this scenario. The first factor is the widespread application of automation technologies that make extensive use of intelligent information processing techniques, a paradigm that has been called Industry 4.0. The second factor is the adoption of the lean philosophy, with its focus on efficiency, effectiveness and waste reduction by emphasizing the core value that must be delivered to customers. Making decisions related to changes in a production environment usually involves considering aspects related to these factors and their relationships, which in most cases are non-trivial. This work is a historical review of the literature of the industrial revolution to the new industry 4.0, added the needs of automation use in lean production systems and supply chain characterization to develop a framework for integration of information systems and technologies in the stages of the chain value manufacturing.

Keywords. Lean, industry 4.0, systems, integration.

Introduction

Companies constantly undergo changes, whether related to habits, cultures or systems. Besides being a matter of survival, evolution is part of the human nature, being the primary factor on globalization. After the mechanization of production, which marks the first industrial revolution in the late 18th century, the industry continues to go through transformations in production and operations management systems. The increasing developments in technology come from the race of competitiveness and resulting need to reduce manufacturing costs in order to reduce the rates of non-value added and eliminating waste. The challenge in meeting the customer with quality, speed and cost/benefit brings up the advent of intelligent industry that emerges in this

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century, yet not intimidating way, as a new industrial revolution, causing managers to seek new production systems whose words synchronization and industrial control are the key to success. Has a few reasons why they believe have led to the new industrial revolution, they are: an increase in developing countries, leading to a greater number of markets that companies need to provide goods; and reduced product life cycles and consequently greater flexibility in the production network has to deal with [1].

This article aims to conduct a literature review about the industrial revolution issues, industry 4.0, industrial automation in lean systems to understand the integration of these issues and develop a framework with systems and candidates technologies composing the manufacturing value chain in order to meet the new industrial demands contemplated in the so called 4th industrial revolution.

1. Literature Review

1.1. Revolutions in Industry

The constant need of companies become increasingly competitive, induces the fact that inclusion of more technologies. This can be observed with the advent of the industrial revolution, which brought with it several benefits such as the main significant productivity increases.

According to the first industrial revolution began with the introduction of mechanical production equipment with the invention of the steam engine at the end of the 18 century [2]. The second, since the beginning of the 20 century, has as main characteristic the mass production, through the lines of production developed by Frederick Taylor, whose source was electricity-powered energy.

The third, in 1969, introduced the programmable logic controller that enabled digital automation systems programming. The programming paradigm still governs the modern automation engineering system of today and leads to highly flexible automation systems and efficient [3]. Based on advanced scanning within the factories, the combination of 2 types of technologies, Internet and domain-oriented of the smart objects (and products), appears to result in a fundamental change of industrial paradigm, which is being called the fourth Industrial Revolution or 4.0 Industry [4].

1.2 Industry 4.0

Since the late eighteenth century industries have undergone three technological developments. The first industrial revolution occurred in the transition from manual labor to machines powered steam, resulting in new opportunities and facilities for industrial production. The second revolution that occurred in the mid-nineteenth century was characterized by the use of electricity, introduction of mass production and the division of labor. In the third revolution, which took place in the 70s and remains today, it is characterized by the use of electronics and information technology for increased automation systems. As shown in the literature review on the application of automation Integrated Manufacturing Computer in the 80s, it is one of the systems that control and automate a production process using information and communication technology.

Thus, we must emphasize that today we are in the middle of where the fourth technological revolution and the birth of a new technology and digital industry known as Industry 4.0. According to the transformation must be intensified by nine grounds of advanced technology [5]: autonomous robots, simulation, horizontal and vertical systems integration, the industrial Internet of things, cybersecurity, cloud computing, additive manufacturing, augmented reality and bi data and analytics. For the development of an Industry 4.0 environment, Deloitte developed a framework with the concepts that form the fourth industrial revolution interface, shown in Figure 1.

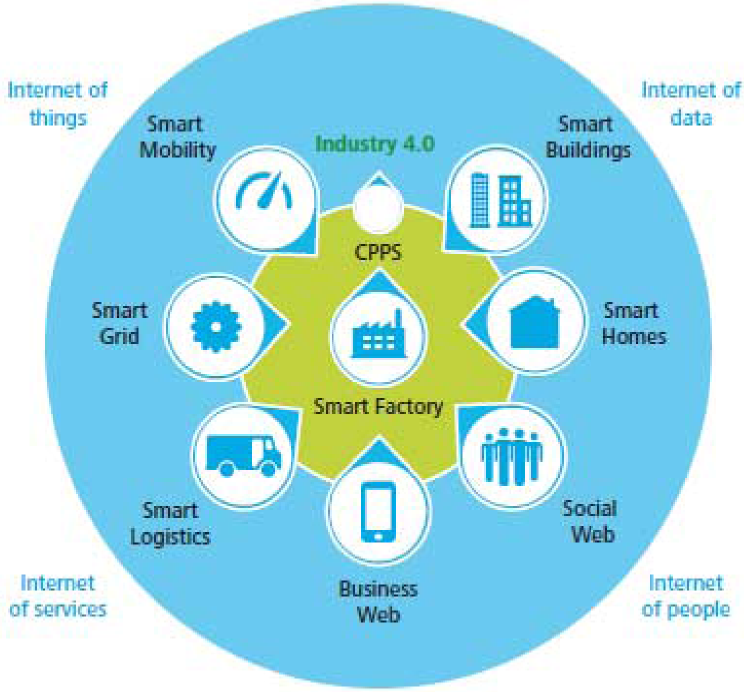

Figure 1. Nine technologies that transform the industrial production.

The central importance of I4.0 is the interface between other intelligent infrastructure such as smart mobility, grid, logistics and intelligent buildings. As the links between business and social networks provide an important role in digital transformation.

1.3 Automation and Lean Manufacturing

With the advent of industrial technology and lean manufacturing needs, automation systems have become increasingly sophisticated seeking higher quality of products and processes and lower cost for customer demand service.

An automated assembly has a system of automated machinery material handling and assembly automatizadode a system to be successful, it takes major product design modifications. The appropriate product design for assembly by no human hands can not be applied directly to an automated assembly, because the capacity of human beings can not be played by machines [6]. For automated production systems are divided in three basic types as shown in Table 1 [7].

Table 1. Types of automation.

Types of automation	Characteristics
Rigid automation	High initial investment in equipment; Higher production rates; Flexibility on the equipment in the room variety of production.
Programmable automation	High investment in equipment; Low production rates; Flexibility to deal with the variations and changes in the product; Highly adaptable for batch production.
Flexible automation	High investment in custom engineering system; Continuous production of a wide range of products; Flexibility to cope with changes in product design.

Second we consider nine reasons to automate a production system [7], they are: i) increase productivity; ii) Increasing productivity; iii) reducing production costs; iv) minimize the effects of the shortage of workers; v) Reducing or eliminating manual and administrative tasks routines; vi) To increase worker safety; vii) improve the quality of the product; viii) Decrease production time; ix) perform processes that can not be performed manually; x) Avoid the high cost of no maintenance.

In the present scenario many industrial automation projects are intertwined with information technology. The link between these technologies provides important data on the shop floor to the management level. The World Wide Web and the new information technologies allow greater integration of software and hardware systems beyond the borders of the company [8]. But the Web can be an inhibitor because it can pose security risks of the automated system, such as hackers and viruses. For the standardization and development of integration models of this system will need to expend much effort.

The most widely used AT and IT integration models are: Computer Integrated Manufacturing (CIM) or Computer Integrated Manufacturing and ISA-95 of the International Society of Automation or International Automation Society. The following is a summary of each model.

For computer integrated manufacturing activities involving the processing of information that provide data and knowledge necessary to the successful manufacture of the product [7]. They are designed to perform four basic functions of production: i) business functions; ii) product design; iii) Production Planning; iv) Production control. There is a hierarchical model of automation represented by a pyramid [9]. On the first, lower level are the active output devices of the system from the controller commands. In the second level are the systems of individual drivers of industrial plant equipment. Level 3 consists of the computers, with supervision order. At level 4 is done the total production control, production and programming. Finally, level 5 runs strategic planning.

The ISA-95 model is a standard for Control and Business Systems Integration which is applicable in continuous processes, batch and discrete. According to the ISA-95 2009 model and ISA-95 terminology manual can be used to generate information which will be exchanged between systems to production systems, finance and logistics, sales, maintenance and quality. The ISA-95 model consists of four levels [9]: i) Level 1: composed of the sensors of the plant; ii)Level 2 consists of the automation functions for monitoring and control equipment; iii) Level 3: This level consists of the functions of Manufacturing Execution System (MES) - scheduling, allocation, resources, etc.; iv)

Level 4: This level consists of the functions of the Enterprise Resouce Planning (ERP) - scheduling, quality management, etc.

1.4 Logistics and supply chain

The logistics alone has a fundamental role in all organizations, since it is through it that makes it possible to supply the production with the raw materials needed, as well as supporting tools and other inputs to the processing phase. It is also responsible for controlling all the information flow of materials and information, including those that are received and/or sent to stakeholders.

According to Logistics is that part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of products, services and related information from the point of origin to the point of consumption in order to meet the needs of customers [10].

Already the supply chain is concerned mainly with the production, distribution and sales of physical products [11]. She is managed by means of information systems that facilitate the integration and sharing of information between the company and the chain itself. Such integration is built on four levels of functionality [12], are: 1) transaction systems; 2) managerial control; 3) analysis of decisions and 4) strategic planning, along with some major components as:

- Enterprise resource planning (ERP-Enterprise Resource Planning) or legacy systems;
- Communication systems;
- Execution systems;
- Planning systems.

The need for flexibility and changeability found in production, from the desire for individual products (customized products) and the growing influence in buying behavior by global trade and logistics, causes the I4.0 has a significant impact on logistics, mainly for being related to supply chain management considering the flow of information and materials [13]. In addition to this fact, it is directly related to evolution of identification of disturbance processes, both internally and outside, covering the entire value chain.

2. Development

To facilitate the application of the implementation I4.0 in a particular organization, it has a model that assists in the identification of the implementation of this new industry in an organization [14].

2.1. Application of an identification model of Industry 4.0

The model prepared [14], shown in Figure 2, consists of five horizontal levels that are grouped by: technology, benefits and applications. This model is used to illustrate what the possible scenarios of Industry 4.0 application, ie, the implementation can only exist as the criteria levels are met.

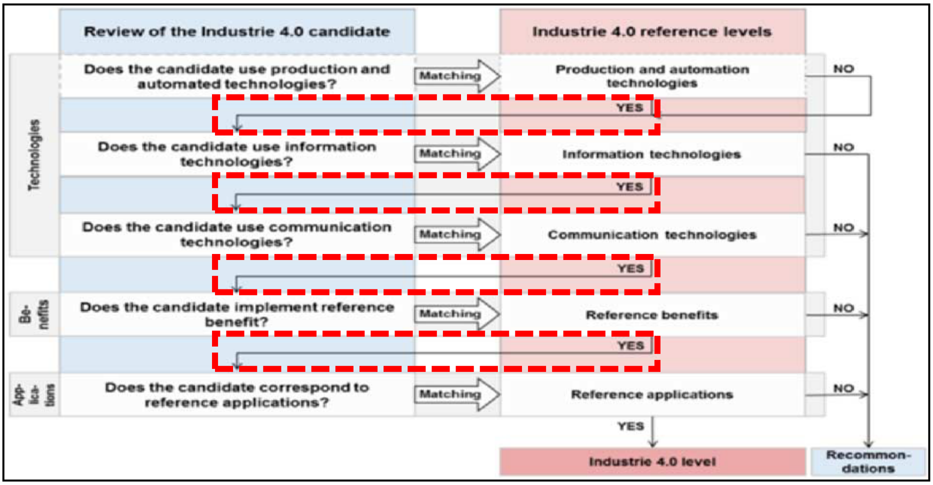

Figure 2. Model of level to identifying applications in Industry 4.0.

Based on the study of the authors, they pose as essential that at least one criterion for each level, except the first, be entertained and there are three groups to be satisfied.The last two require a preliminary table for query, which are represented in Figures 3 and 4.

	High priority		Minor priority
Benefit	▪ Real-time capability ▪ Security ▪ Networking ▪ Scalability ▪ Transparency ▪ Flexibility ▪ Modularity ▪ Decentralisation	▪ Self-organisation ▪ Autonomy ▪ Remote diagnosis ▪ Identifiability ▪ Traceability ▪ Monitoring ▪ Energy efficiency ▪ Assistance	▪ Shortening of development time ▪ Intuitive operability ▪ Flow of information to employees ▪ Automation ▪ High transfer rates ▪ Shapeless workpiece manufacturing

Figure 3. Benefits reference.

	Human	Technology	Organization
Reference application group	Human-machine interaction	Networking	Value added
Reference applications	▪ Enable ageing- and ageappropriate working conditions	▪ Intelligent products are information carriers, adressable and identifiable	▪ Mediation of regional added value
	▪ Expand the scope and the qualifications	▪ Machines load data themselves to expand their capabilities	▪ Using a Suppliers-Cloud to find alternative suppliers in real time

Figure 4. Application reference.

2.2. Proposed framework for systems integration in the value chain

For all levels discussed in Section 1.3, the responses related to the current status of the supply chain were positive, whose explanation is demonstrated in Table 2. To illustrate in which actors the technologies mentioned above are inserted along the chain, as discussed in Figure 5, whose construction was based on data collected in an automotive company of the metropolitan region of Curitiba, PR.

Fit to add that the ERP (Enterprise Resource Planning) is in short a system integration and information management operational procedures, administrative and even an organization management [15]. For this, he was considered to be comprehensive across the supply chain, as the system that could unite all the others. However, this is not yet a reality within the context of I4.0.

Table 2. Explanation of answers.

<table>
<tr><th>Level</th><th>Answer</th><th colspan="3">Description</th></tr>
<tr><td>1</td><td>Yes</td><td colspan="3">The automation is increasingly present in the logistics scenario.
Example: there are available on the market use of tele stand-alone carriers in conjunction with information systems for use in stock, apart from self guided vehicles for transport of parts and stands as container handling pickings.</td></tr>
<tr><td>2</td><td>Yes</td><td colspan="3">Due to interface with the system of communication technology by means of devices and tracking system and connection to multisetores agents within the organization.
Example: using RFID (Radio-Frequency IDentification) chips to fellowship with ICT (Information and Communications Technology). Serves both for inventory, how to schedule production and PPC (Production Planning & Control).</td></tr>
<tr><td>3</td><td>Yes</td><td colspan="3">Because communication with the information system of production scheduling, as production sequencing and identification of necessary parts.
Exemple: Use of interns ICT (Information and Communications Technology) in conjunction with AGV (Automatic Guided Vehicle), to transport spare parts in stock for production lines.</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Yes</td><td colspan="3">Main benefits granted</td></tr>
<tr><td colspan="2">Group 1 (high priority)</td><td>Group 2 (low priority)</td></tr>
<tr><td colspan="2">1) Flexibility: due to differentiation of the models as requested by client customization and need to reduce inventory to reduce costs.
2) Modularity: due to the supply of parts and components in kits as sequencing models, to gain in agility.
3) Monitoring: due to quality management, process mapping and control indicators (even with statistical reports generated by software).
4) Autonomy: taking into account the perfect shooting of internal communication and information systems at the moment with the interface, when a piece is taken from stock, is automatically updated your quantity and at the right time a new application is requested via as to a supplier.</td><td>1) Intuitive Operability: due to especifico.Alguns training systems require processes require constant updates and consequently new formations should be performed.
2) Flow of Information to Employees: because the information which is passed on to operators through information and communication systems.</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">Yes</td><td colspan="3">*Main applications met*</td></tr>
<tr><td>Man-machine interaction</td><td>Technology</td><td>Organization</td></tr>
<tr><td>Operations are built only with validation of ergonomics.
Example: using collaborative robots that can work in conjunction with an operator.</td><td>Through the system of Information and Communications Technology (ICT) and connection to the multi sectors.
Example: Investments in automation of stocks, as the vertical automated inventory using teleporters and communication with an information system and/or RFID.</td><td>N/A</td></tr>
</table>

From the results found in the above model, it was possible to draw up the framework for integration of systems and technologies along the supply chain chain of the manufacturing industry. The framework to integrate systems in the chain value of manufacturing is available in Figure 5.

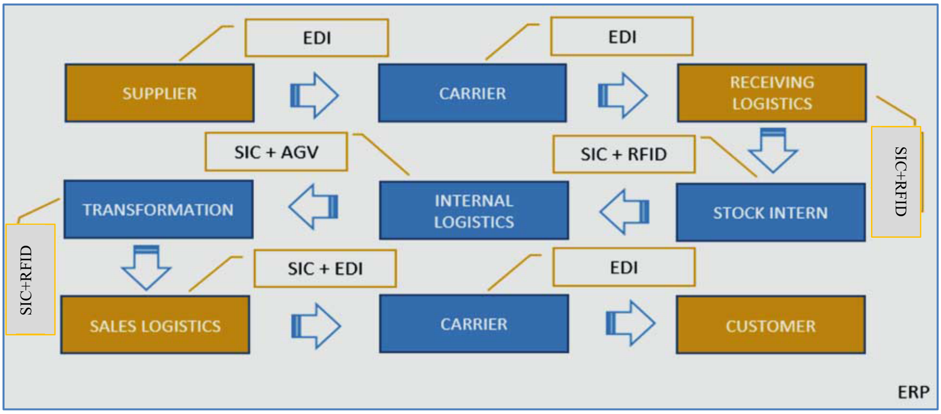

Figure 5. Framework to integrate systems in the chain value of manufacturing.

3. Conclusion

Field devices, machines, plants and factories will be increasingly connected to a network. They will be available as data objects on the network and can store data in real time. Therefore, they become searchable, exploitable, and response on the network [3]. This will lead to an explosion of objects and data available, accessible from anywhere. Despite the many benefits identified in the literature review, it is necessary to consider some points of attention to the implementation of I4.0 along the chain, because the process requires the integration of production, systems and management stakeholders. So that there is effective communication between all users and processes is necessary that the systems work with the same type of communication protocol (language) and this is a big challenge.

Another key factor to be considered is that process data require cloud storage, which imposes requirements like: agility of the transmission of information, storage, connection speed, virtual security in conjunction with confidentiality of information. However, according to scenario in which the Brazil, beyond the need for investment in transport, there's the matter of internet network infrastructure, such points would be a major obstacle to the implementation of successful I4.0, at least until the next developments.

However, according to scenario in which the Brazil, beyond the need for investment in transport, there's the matter of internet network infrastructure, such points would be a major obstacle to the implementation of successful I4.0, at least until the next developments in these fields.

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A Framework for Applying Additive Manufacturing to Consumable Process Parts

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Abstract. The growing competitiveness among automakers and other organizations of the automotive supply chain has been the trigger for innovation in production technologies so that objectives and goals can be met. In highlight, one of the main innovations being adopted as a source of cost reduction, reduced processing times and process flexibility are the so called 3D printers or additive manufacturing technologies. There are currently 13 different types of additive manufacturing technologies and the choice of which technology to use is based on different factors such as unitary cost of the processed part, processing time, accuracy, surface finish, and mechanical properties such as thermal resistance, among others. In order to assist in this selection process, this work presents a preliminary framework for applying additive manufacturing technologies to consumable process parts, such as nozzles, fixtures and support devices, which are not incorporated in the final product, but because of wear or destruction, need frequent replacement in the production process. This framework is based on a set of exploratory case studies conducted in an organization of the automotive industry and the literature on additive manufacturing and decision-making methods. The framework is composed of a set of criteria to be evaluated when assessing which consumable process part may be matched by a specific additive manufacturing technology, and a process that guides the application of these criteria. The framework's utility, usability and feasibility is finally discussed.

Keywords. Additive manufacturing, consumable process parts, selection framework, decision-making methods

Introduction

The manufacturing companies are looking for approaches that optimize production processes in terms of speed, cost reduction and product quality in order to increase profit margins [1], assuming therefore a position of major player in the segment it operates or, at least, achieving the outlined strategic objectives.

The search for improvements of results and production processes leads organizations to seek resources and tools that are in the context of technological and innovative trends. On this basis, there is a prominent issue in today's business

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environment, the industry 4.0, which has the intention to interconnect the entire production chain of an organization, end to end, adding value to it. The concept seems simple, but there are several factors that should be considered and analyzed, including: autonomous robots, simulation, horizontal and vertical integration, Internet of Things (IoT), cybersecurity, the cloud, additive manufacturing (AM), augmented reality, big data and analytics [2]. These factors, each with its peculiarity, are able to assist in the strengthening, development and improvement in processes of companies, offering innovative technologies.

One believes that the additive manufacturing is able not only to produce individual prototypes and components, but use the technology for the production of small batches of customized products that offer advantages, such as: reduce transportation and inventory; flexibility to changes in projects and sophisticated visualization capabilities [1].

Therefore, the AM (3D printing) is one of the most technologies prominent today, reaching segments like: food, automotive, construction, retail, among others. As the range of areas is large, the diversity of 3D printing equipment is also large, because each one meets a specific need. The AM technologies differentiate themselves by: physical form of raw material, production process, types of raw materials, printing speed, among others [3].

Thus, the main question to be answered is: “How to identify the best additive manufacturing technology to be chosen for a given process or product, based on certain factors to be analyzed?”. To answer this question a preliminary framework of decision-making will be produced. It will be preliminary because the parts will be evaluated according to the framework, but will not be printed in technology indicated and will not be compared to the other to check the veracity of the statement obtained by the model application.

The parts selected to test the framework are consumable process parts of the automotive industry located in the state of Paraná. These parts do not belong to the final product, but assist in the production thereof, such as: jigs, supports, robot accessories, among others. The choice for this type of parts was due to the fact it was not found cases in the literature of models of decision-making for the production these parts by additive manufacturing technologies, and the cases found are meant to end parts.

1. Literature Review

1.1. Additive Manufacturing (AM)

Additive Manufacturing (AM) is defined as a process of joining materials to make objects from the 3D model data, usually layer upon layer, unlike subtraction manufacturing methodologies [4, 5]. In other words, additive manufacturing technologies build objects from a CAD model, which will undergo a conversion process from a three-dimensional model to a layered model (.stl file), which will be read by the machine and printed.

Due to the high number of 3D printing technologies, Table 1 [3] consolidates thirteen types of technologies, highlighting: the type of process, raw materials, the main advantages and disadvantages. In addition, it’s important to analyze some factors that should be considered when choosing the production process and the part that will be produced. Thus, the factors listed below may be considered in the framework.

Table 1. Types of additive manufacturing (Adapted from Cotteleer *et al.* [3]).

Technology	AM Process	Typical materials	Advantages	Disadvantages
Stereolitography (SLA)	Vat polymerization	Liquid photopolymer, composites	Complex geometries; detailed parts; smooth finish	Post-curing required; requires support structures
Digital light processing	Vat polymerization	Liquid photopolymer	Allows concurrent production; complex shapes and sizes; high precision	Limited product thickness; limited range of materials
Multi-jet modeling	Material jetting	Photopolymers, wax	Good accuracy and surface finish; may use multiple materials (also with color); hands-free removal of support material	Range of wax-like materials is limited; relatively slow build process
Fused deposition modeling (FDM)	Material extrusion	Thermoplastics	Strong parts; complex geometries	Poorer surface finish and slower build times than SLA
Electron beam melting	Powder bed fusion	Titanium powder, cobalt chrome	Speed; less distortion of parts; less material wastage	Needs finishing; difficult to clean the machine; caution required when dealing with X-rays
Selective laser sintering (SLS)	Powder bed fusion	Paper, plastic, metal, glass, ceramic, composites	Requires no support structures; high heat and chemical resistant; high speed	Accuracy limited to powder particle size; rough surface finish
Selective heat sintering	Powder be fusion	Thermoplastic powder	Lower cost than SLS; complex geometries; no support structures required; quick turnaround	New technology with limited track record
Direct metal laser sintering	Powder bed fusion	Stainless steel, cobald, chrome, nickel alloy	Dense components; intricate geometries	Needs finishing; not suitable for large parts
Powder bed and inkjet head printing	Binder jetting	Ceramic powders, metal laminates, acrylic, sand, composites	Full-color models; inexpensive; fast to build	Limited accuracy; poor surface finish
Plaster-based 3D printing	Binder jetting	Bonded plaster, plaster composites	Lower price; enables color printing; high speed; excess powder can be reused	Limite choice of materials; fragile parts
Laminated object manufacturing	Sheet lamination	Paper, plastic, metal laminates, ceramics, composites	Relatively less expensive; no toxic materials; quick to make big parts	Less accurate; non-homogeneous parts
Ultrasonic consolidation	Sheet lamination	Metal and metal alloys	Quick to make big parts; faster build speed of newer ultrasonic consolidation systems; generally non-toxic materials	Parts with relatively less accuracy and inconsistent quality compared to other AM processes; need for post-processing

Technology	AM Process	Typical materials	Advantages	Disadvantages
Laser metal deposition	Directed energy deposition	Metals and metal alloys	Multi-material printing capability; ability to build large parts; production flexibility	Relatively higher cost of systems; support structures are required; need for post-processing activities to obtain smooth finish

1.2. Choice of Parameters

Based on the work of some authors, the list below gives the main parameters to be weighed in the choice of technology and evaluation of parts to be produced, such as:

- complexity of the part, customization and production volume [6];
- dimensional accuracy, surface roughness, cost, processing time, material properties (tensile strength and elongation) [7];
- purpose of the product, material needed in its composition, dimensional accuracy, cost, processing time, necessary detail, surface finish [8];
- print speed, cost, resolution, accuracy, material properties and color [9];
- cost, amount of material used, processing time, amount of necessary support, accuracy andsurface finish (roughness) [10];

In the face of the factors listed above, there is a need to select which the main points to be observed in the selection of an AM technology to be the best in order to meet the needs and generate the expected results. Therefore, the next topic is related to the decision-making model which will serve as basis for the development of the framework that will assist in decision-making for choosing an AM technology.

1.3. Multiple Criteria Decision-Making

Multiple Criteria Decision-Making (MCDM) techniques can be classified into two main categories: Multiple Objective Decision-Making (MODM) or Multiple Attribute Decision-Making (MADM). Therefore, to know in which category the decision-making technology belongs it is necessary to understand the meaning of objective and attribute. Thus, follow the definitions: the objectives are like the reflection of the desire of decision-makers and presume the direction in which they want to work; and attributes are characteristics that represent properties or capabilities of alternatives to meet the need and/or wishes of decision-makers [11]. As soon, as the main aim of the paper is to create a model that helps to identify the best AM technology based on some criteria, it should be taken into account to create the framework only existing methods related to MADM.

The main MADM methods which may assist in the framework development are: simple weighting (SAW), TOPSIS, ELECTRE and AHP. The AHP is used as the basis for creating the preliminary framework as it takes into account the qualitative part of the analysis as well as the quantitative; and through it, it is possible to choose the alternative that contributes to achieving the criteria that are most important for each analyzed parts. AHP, thus, will be briefly explained next.

1.3.1. Analytic Hierarchy Process – AHP

The AHP is a tool used to facilitate the analysis, understanding and assessment of the problem by dividing it into hierarchical levels. [12]. It was developed by Thomas L. Saaty in the early 70s and is divided according to the following steps [13]:

- structuring the problem hierarchically showing the key elements and the relationships between criteria and alternatives;
- organizing criteria and alternatives in an matrix for pairwise comparison;
- comparing alternatives consistently, using the knowledge of the business, impressions and sensations that have on the subject. Preferably using the numerical scale developed by Saaty;
- calculating the weights of alternatives and criteria within the established hierarchy;
- calculating the consistency of relation to evaluate whether the judgment made by the decision maker is coherent and will not lead to a wrong decision;
- summarizing the results and assemble the final scale of values to the alternatives ordered by preference.

The results obtained from the analysis performed through the AHP application is the consensus of the best alternative proposal with the main criteria targeted to achieve the solution to the problem or meet the established objective. Therefore, in this case, the main objective is to choose the best additive manufacturing technologies that meets the main criteria for each parts. This will be done as the preliminary framework described below.

2. Development of preliminary framework

For the development of the preliminary framework, it will be considered only the three main technologies currently used: SLA, FDM e SLS. The main characteristics of these technologies were mentioned in Table 1.

The attributes mentioned in the article were compiled and classified and the list that follows contains the attributes that will be assessed to assist in the identification of AM technologies most suitable for use in each case: processing time, accuracy, surface finish, unitary cost, mechanical properties and thermals (resistance) and complexity of the product. The purpose is to use principles of AHP to rank the relative priority of each criterion used in the analysis of each part and from this, opt for the technology in which the parts will be printed.

To better understand this approach, a step by step of the preliminary framework follows:

Step 1: identifying the part to be printed, its features and required characteristics, according to the list of attributes chosen by the authors of the article mentioned at the beginning of this section. For the example to be developed:

- Part: protective cover.
- Function: protection of welding robots end effector.
- Required characteristics: impact resistance, processing time and unitary cost.

Step 2: apply the principles of AHP to determine the ranking of criteria through an *n* by *n* matrix, such as Table 2. The matrix must be formulated for each part to be printed. Each row and column on the of this table belongs to a chosen criterion in Step 1. To assist in filling out this matrix, Table 3 (see appendix) mut be consulted, that has been adapted from the original built by Saaty in 1977.

Table 2. Example of ranking of criteria for the welding robot protective cover.

		CRITERIA			CALCULATION		
		Impact resistance	*Processing time*	*Unitary cost*	*Product*	*Geometric mean*	*Relative priority*
CRITERIA	*Impact resistance*	1.00	7.00	9.00	63.00	3.979	0.762
	Processing time	0.14	1.00	7.00	0.98	0.993	0.190
	Unitary cost	0.11	0.14	1.00	0.02	0.249	0.048
					Sum	**5.230**	**1**

Table 3. Importance table (Adapted from Saaty [13]).

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

To complete Table 2, one shall consider the criterion chosen as priorities for the part (Step 1). The filling of the table should occur in two ways: a) to fill the left side of the table, related to criteria, according to the information entered in step 1 and the analysis set out in Table 3; and b) to fill the right side of the table, related to calculation; the details of how to be filled are as in the example below. This should be done by the people involved in the application of the method, typically experts in the domain.

Diagonally across the table (left side – related to criteria) values are equal to 1, because as comparisons occur pairwise and should be analyzed according to Table 3 when comparing the impact resistance with itself, it is known that it is of equal importance; soon the number of importance is equal to 1. The other comparisons are:

- Impact resistance and processing time: as the parts suffers severe impacts that can damage it, the impact resistance is much more important than processing time. Therefore, the intersection of these criteria receives the number 7 (according Table 3). As pairwise comparisons occur when the comparison is processing time vs. impact resistance, the degree of importance will be the inverse of other comparison. Therefore, the intersection of processing time vs. impact resistance receives the number 1/7 = 0.14.

- Impact resistance and unitary cost: as the function of the part is to protect the equipment and the operator, keeping the part intact, the impact resistance is extremely more important than the unitary cost. So, the intersection of the criteria receives the number 9.
- Processing time and unitary cost: as the item is for protection, the time to process the part is much more important than the final cost of it, because it is a security issue. Thus, the intersection of the criteria receives the number 7.

The part of the calculation in Table 2 is performed as follows:

- Product: multiplication of the importance values in each line. That is, in the first line, the product column, the value is 63, which corresponds to multiplication 1, 7 and 9.
- Geometric mean: it's the nth-root of the product with exponent equal to the number of criteria used. For example, first line: $\sqrt[3]{63}=3{,}979$.
- Relative priority: it's the geometric mean value divided by the sum of all of the geometric means. The relative priority shows which are the most important criteria, the larger the value of the priority, the more important the criterion is.

Step 3: according to the ranking obtained in Step 2, one has to analyze Table 4, that classifies the alignment to the criteria for each type of technology. The table was developed based on the identification of the characteristics of the technologies found in the literature review (Table 1) according to the interpretation of scientific literature.

Table 4. Criteria vs. technologies.

	Technologies		
Criteria	*SLA*	*SLS*	*FDM*
Surface finish	excellent	good	regular
Accuracy	excellent	good	regular
Impact resistance	regular	good	good
Flexural strength	low	excellent	excellent
Unitary cost	high	high	medium
Processing time	good	excellent	good
Product complexity	excellent	excellent	good

Example: according to Table 4, the most important item for the part is the impact resistance, followed by processing time and unitary cost. In Table 5, impact resistance is best in SLS and FDM. To decide, which of these is best suited for this part, one has to analyze the second most important criterion, processing time. Between the two aforementioned technologies, the processing time is better on the SLS. Therefore, the most appropriate technology for the production this part is the SLS.

Next section will demonstrate three applications of the preliminary framework also belonging to the exploratory cases performed in the same organization in which the previous example was developed.

3. Cases of the preliminary framework

3.1. Case 1 – Mastic nozzle applicator

Step 1:

- Part: Nozzle applicator Mastic.
- Function: to apply glue on the windshield of vehicles.
- Required characteristics: surface finish (roughness), processing time, accuracy and unitary cost.

Step 2:

- Roughness and processing time: roughness is essential to the part, because the applied glue can adhere to imperfections of the inner wall of the nozzle, dry and, consequently, obstruct passage. Therefore, this criterion is essentially more important than processing time. The degree of importance is not extreme, because as the use of the part is 4 units per day, the processing time may not be high.
- Roughness and accuracy: roughness is also more important than accuracy due to the fact mentioned in the previous item. However, the accuracy is also important, due to the fact that this is coupled to a robot.
- Roughness and unitary cost: the roughness is much more important than the unitary cost, because it undermines the proper functioning of the part and advancement in the production process.
- Processing time and accuracy: accuracy is moderately more important than processing time, but both are essential for the proper functioning of the part and to the advancement of the production process.
- Processing time and unitary cost: processing time is substantially more important than the cost due to the demand.
- Accuracy and unitary cost: accuracy is essentially more important than unitary cost, due to the accuracy required for the proper functioning and coupling of the part.

After identifying the degree of importance of the attributes and performing the calculations, Table 5 was constructed.

Table 5. Step 2 - Mastic nozzle applicator.

		CRITERIA				CALCULATION		
		Surface finish	*Processing time*	*Accuracy*	*Unitary cost*	*Product*	*Geometric mean*	*Relative priority*
CRITERIA	*Surface finish*	1.00	5.00	5.00	7.00	175.00	3.637	0.608
	Processing time	0.20	1.00	0.33	5.00	0.330	0.758	0.127
	Accuracy	0.20	3.00	1.00	5.00	3.000	1.316	0.220
	Unitary cost	0.14	0.20	0.20	1.00	0.006	0.274	0.046
						Sum	**5.985**	**1**

Step 3: Based on the ranking of criteria, Table 6 shows that the best technology for the production of the nozzle is the SLA. Because, considering all the identified criteria, each according to their priority, the SLA meets the two main criteria.

Table 6. Step 3 - Mastic nozzle applicator.

	Technologies		
Criteria	*SLA*	*SLS*	*FDM*
Surface finish	excellent	good	regular
Accuracy	excellent	good	regular
Processing time	good	excellent	good
Unitary cost	high	high	medium

3.2. Case 2 – Welding support

Step 1:

- Part: support for welding.
- Function: support used in the welding of car bodies.
- Required characteristics: surface finish (roughness) and accuracy.

Step 2:

- Roughness and accuracy: as the main function of this part is to support the car bodies, it is necessary that it does not damage it. Therefore, roughness is extremely more important than accuracy.

Table 7 contains the corresponding values of the part analyzed.

Table 7. Step 2 – Welding Support.

		CRITERIA		CALCULATION		
		Surface finish	*Accuracy*	*Product*	*Geometric mean*	*Relative priority*
CRITERIA	*Surface finish*	1.00	9.00	9.00	3.000	0.900
	Accuracy	0.11	1.00	0.11	0.332	0.100
				Sum	**3.332**	**1**

Step 3: The technology chosen as the best option for printing this part, according to Table 8 is SLA..

Table 8. Step 3 – Welding support.

	Technologies		
Criteria	*SLA*	*SLS*	*FDM*
Surface finish	excellent	good	regular
Accuracy	excellent	good	regular

3.3. Case 3 – Non-rotating sleeve

Step 1:

- Part: non-rotating sleeve.
- Function: the analyzed piece works as a clutch for a system.
- Required characteristics: accuracy, impact resistance and unitary cost.

Step 2:

- Accuracy and impact resistance: the impact resistance is much more important than accuracy, because if the part has great accuracy and little resistance, the service life will be reduced and problems with frequent changes and maintenance will occur more often.
- Accuracy and unitary cost: the accuracy is essentially more important than the cost, because it's the accuracy that will ensure the proper functioning of the part and the necessary fit with the other parts set.
- Impact resistance and unitary cost: as mentioned above the impact resistance is a decisive criterion for the proper functioning of the production process. Therefore it is extremely more important than unitary cost.

Table 9 contains the corresponding values of the analyzed part.

Table 9. Step 2 - Non-rotating sleeve.

		CRITERIA			CALCULATION		
		Accuracy	*Impact resistance*	*Unitary cost*	*Product*	*Geometric mean*	*Relative priority*
CRITERIA	*Accuracy*	1.00	0.14	5.00	0.70	0.888	0.172
	Impact resistance	7.00	1.00	9.00	63.00	3.979	0.773
	Unitary cost	0.20	0.11	1.00	0.02	0.281	0.055
					Sum	**5.148**	**1**

Step 3: The best technology to be chosen, according to Table 10, is the SLS, because it will meet the first two criteria of the ranking with a good quality. While SLA serves better in terms of accuracy, but the impact resistance is regular.

Table 10. Step 3 - Non-rotating sleeve.

	Technologies		
Criteria	*SLA*	*SLS*	*FDM*
Impact resistance	regular	good	good
Accuracy	excellent	good	regular
Unitary cost	high	high	medium

4. Conclusions and Limitations

The model contains principles of AHP, but its main base are the criteria that must be analyzed in each piece and how each technology meets these criteria. The definitions were established according to the literature and to check the framework efficiency it is necessary to produce the part in the technology indicated and in the others; in order to compare the results and validate the preliminary framework. Therefore it is not a final framework but a preliminary framework. Anyway, the preliminary framework is important for the area of 3D Printing, because to have theoretical background and easy to apply.

To realize the full study, ie not only the application of the model, but also the production of parts, is indicated consider the limitations of each technology and then choose the parts. The most suitable is to consider mainly the parts that can be produced in the simplest technology that is the FDM, because then it is considered that the others can also be produced; and what it will be really tested is the preliminary framework.

This framework still needs further work to be fully validated. Experts need to be consulted in relation to the factibility of the technology selected for each part according to the criteria, as well as the definition of the criteria needs to be improved and better systematized – it still uses much of the opinion of domain experts that are working or interested in the parts being produced.

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A Value-Focussed Decision Framework for Manufacturing Research Environments

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Abstract. Industrial research centres have a requirement to deliver new products, technologies and processes which can be applied in manufacturing environments. The dynamic nature of these centres has attracted a growing need from industry for value-focussed decision based systems to be in place that include accurate and reliable cost estimation techniques. A holistic solution which is able to manage the dynamic and complex nature of knowledge within these environments is required. This paper offers the potential to provide a solution for a value-focussed cost estimation and decision framework capable of supporting technology selection within these environments.

Keywords. Cost engineering, decision making, uncertainty.

Introduction

To successfully mature a technology to full production requires significant investment in research and development, which must be optimally managed within the technology planning process [1]. The Manufacturing Capability Readiness Level (MCRL) system provides a rigorous gate review structure to ensure consistent process quality throughout development programmes. Stages 3-6 are the pre-production stages in which a technology is proven for production and requires significant R&D investment. These stages are particularly difficult to traverse as funding for R&D is less readily available than earlier stages and the technological challenges involved in maturing the technologies to a commercial scale are significant. The ‘valley of death’ idiom is used, in manufacturing environments, to reflect this difficulty, describing a valley in which technologies “die” before they are fully implemented [2]. The high value catapult centres have been designed to address this problem by providing industry with facilities and expertise needed to establish their technologies before they are scaled up to full production, thus reducing the risk to industry.

The major challenge in pre-production is the magnitude of uncertainty surrounding novel technologies; this can significantly affect the confidence in decision making.

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1. Background

1.1. Technology development

The dynamic and uncertain nature of technology maturity costs time and money and complicates decision making. Improved knowledge management, identification of cost drivers and appropriately informing the direction of R&D within the pre-production stages has the potential to address these issues. As illustrated in Figure 1, the R&D investment could be reduced and financial returns could be greater and achieved sooner. Providing decision makers in these environments with transparent, well- defined knowledge from historical, current and evolving sources of both qualitative and quantitative data could achieve this. Moreover the more detailed knowledge provided by this approach has the potential to be projected backwards to influence academic research.

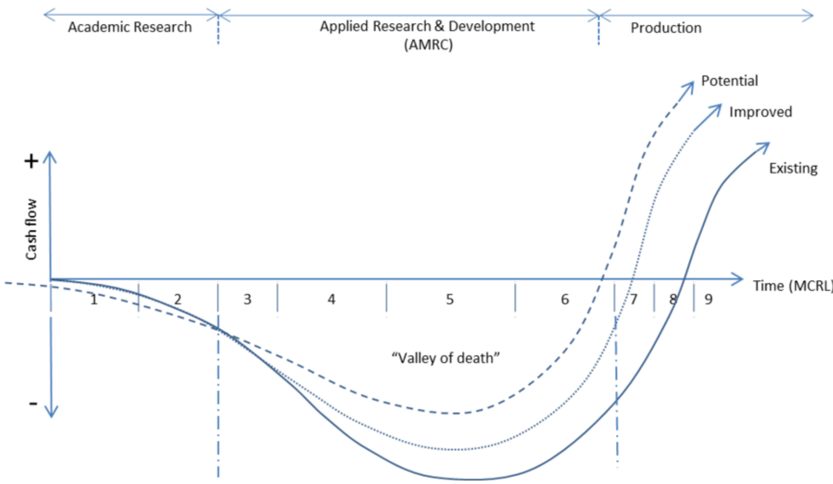

Figure 1. Traversing the "valley of death", adapted from [2].

1.2. Knowledge management

The task of developing a suitable means of managing knowledge which can be in many forms and residing in many places is particularly complex.

Knowledge evolves, with the value of information increasing, from raw data capture to processed and synthesised data that is able to support informed decisions. All forms of knowledge are present to varying degrees in industrial research centres and the specific requirements for elicitation and management need to be addressed to enable the most effective decisions to be made.

The types of knowledge that are required for value based decisions are described in Table 1. Value-focussed decision making resides in the discipline of cost engineering; the state of the art and limitations of existing methods is discussed in the next section.

1.3. Cost Engineering

Cost engineering refers to the application of scientific principles and techniques to solve a variety of cost related problems. The practice is carried out throughout the project life-cycle using cost models, tools and databases, whilst employing expert judgement concerning the specifics of the activity of interest. Often the output of cost engineering is the input to a decision making process [3].

Table 1. Knowledge requirements for value-focussed decision framework.

Title	Type	Description	The role of knowledge management
Cost estimates	Quantitative	Time Cost rates Resource requirements Depreciation Fixed and variable costs	Causal relationships Uncertainty Variability Normalisation Units
Capability and maturity data	Quantitative & Qualitative	MCRL Performance data.	
Expert opinion	Qualitative	Lessons learned Estimates.	Requires codification

Cost engineering methods span many industry sectors [4]–[6]. It is well known that targeting cost reduction in early stages of product design is beneficial [7]–[9]. However, very few publications specifically target cost during the early stages of R&D. Methods compare alternative designs, processes and, to a lesser extent, technologies [5], [10] but do not offer a value-based decision making solution for identifying where technology research and development opportunities exist.

Cost modelling maps a product (or process) parameter (or feature) to an economic value [11], [12]. The method is used to determine cost drivers and their sensitivities.

A distillation of the cost engineering literature indicates good practices relevant to the development of the proposed framework:

1. Definitions of cost and value must be agreed [13].
2. Data must be classified and centrally stored to enable knowledge sharing, sensitivity analysis and updating to occur [14], [15].
3. Methods to capture, represent and manage uncertainty is vital [16]-[18].
4. Cost estimation methods depend on the level of detail available [12], [17].
5. Feedback loops enable experts' knowledge to inform decisions [15], [19].
6. Stakeholder thinking and knowledge elicitation techniques reduce the likelihood of bias disrupting the accuracy of the data [20],[21].
7. Cost management systems must be aligned with the current governance [5], [22].

Research gaps identified in a review of cost engineering in the UK are summarised in Table 2.

The prominence of uncertainty and knowledge management related research in this list may signify the difficulties in managing the effect that these aspects can have on the accuracy of cost estimation and so further research will attempt to provide insight into these aspects.

An appreciation of the range of stakeholders holding this knowledge and influencing and driving the industrial requirements is essential for improved decision making and will be discussed in more detail.

1.4. Stakeholder management

The stakeholders not only influence decisions but in many cases provide the knowledge that is required to make those decisions.

Stakeholder analysis can be used to determine the level of interest and influences, views, and expectations of all stakeholders as well as determining where the most valuable knowledge resides. This information is captured within a gated project-review process [23] in centres like the one described. A stakeholder analysis matrix can be used to map and manage each stakeholder's level of support and influence [24].

This paper illustrates that to satisfy the requirement for a robust cost engineering framework, a thorough understanding of the complexities in decision making, combined with a way to manage the uncertainties and knowledge, is essential. Using observational methods to diagnose the context and purpose, as well as insights from literature, a conceptual framework is created to demonstrate the theoretical structure of research ideas and concepts for value-focussed decision making.

Table 2. Research gaps in cost enginering [7].

Gaps in engineering research	
Managing uncertainty	A framework for capturing critical uncertainties that impact life cycle costing
	Consideration of aleatory and epistemic uncertainties separately
	Approaches for the qualitative affordability factors
	Trade-offs between customer affordability and manufacturer profitability
	Recognition of uncertainty throughout the life-cycle
	Improved understanding of uncertainty variation through the full life cycle
	Verification and validation of epistemic uncertainties in cost estimation
	More representative LCC model
Knowledge management	Quantitative & Qualitative
Design stage	Qualitative

2. Methodology

This work represents the first stage in a research initiative which aims to establish a link between value-related knowledge management and improved decision making in environments with significant uncertainty. The nature of the research setting is complex. The environment spans internal and external boundaries. The drivers and knowledge required to make cost effective decisions are uncertain and dynamic, and significantly affect the confidence in decision making.

The wider research study is a four year EPSRC and Rolls-Royce Plc funded Engineering Doctorate which aims to:

"Develop, implement and evaluate a framework for value-focussed technology selection, for use in advanced manufacturing research and development."

The aims will be met by the following objectives:

- To identify the stakeholders and their requirements;
- To identify and elicit the extant quantitative and qualitative knowledge, and interrelationships;

- To identify the most suitable methods for handling uncertainty, changing information, and to support decision making;
- To develop and validate the framework, using two case studies, from different phases of the technology readiness scale.

2.1. Mixed methods research

The research aim for this study includes the analysis of quantitative cost data and qualitative insight from experts and is aiming to synthesise both in a way to support decision making. In this regard it lends itself to mixed methods research [25]. Mixed methods can combine approaches, methods, data and types of analysis [26].

3. Preliminary results and discussion

3.1. Contextual model

To gain further insight into the significance of these complexities within applied manufacturing R&D, a piece of exploratory research was conducted on a representative project from the Advanced Manaufacturing Research Centre (AMRC). The aim of the project was to determine the most appropriate tooling for the machining of a novel material. The requirement originated from the driver to reduce the weight of an aircraft. Significant investment is required to establish new manufacturing regimes and so experts at the AMRC were employed to identify the most cost efficient solution. The flow and complexities of knowledge management throughout the project were elicited using semi-structured interviews and captured in a conceptual model (Figure 2).

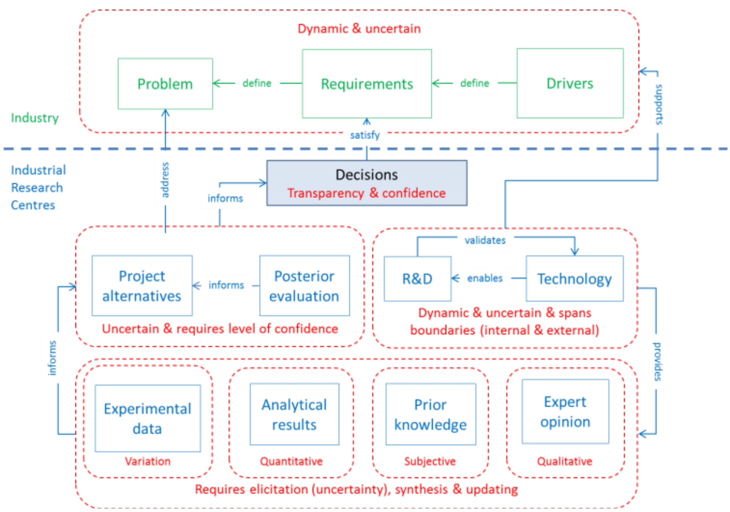

Figure 2. Conceptual model of decision making in manufacturing R&D.

The experts had to draw from existing data and knowledge, as well as conduct R&D to evaluate a set of alternative solutions to the problem. This evaluation was complex due to the requirements in elicitation and management of knowledge as well as the uncertainty which can influence the confidence in the alternatives provided to the customer. When compared to the findings from the knowledge base there are clear synergies in terms of considerations for decision making.

3.2. Conceptional framework for value-focussed decision making

To consolidate the findings from the knowledge base, the model of decision making, and from discussions with stakeholders, a conceptual framework has been developed (Figure 3). The framework breaks down the challenge into three areas: (1) Input - the elicitation of knowledge and to provide a contextual understanding; (2) Process - data consolidation, modelling and analysis; (3) Output - communication and integration of the framework to support decision making. The learning outcomes are then fed back into the framework for updating to occur. The sequence of activities that an organisation could adopt to improve industrial R&D decision making is sketched below:

- **Elicit** and represent existing cost related knowledge including the uncertainties in this knowledge;
- **Consolidate** this knowledge by synthesising the sources of data, building models and mapping the interrelationships;
- **Analyse** the models using interrogation techniques such as sensitivity analysis to determine the drivers;
- **Communicate** the knowledge and uncertainties in a way useful for decision making.

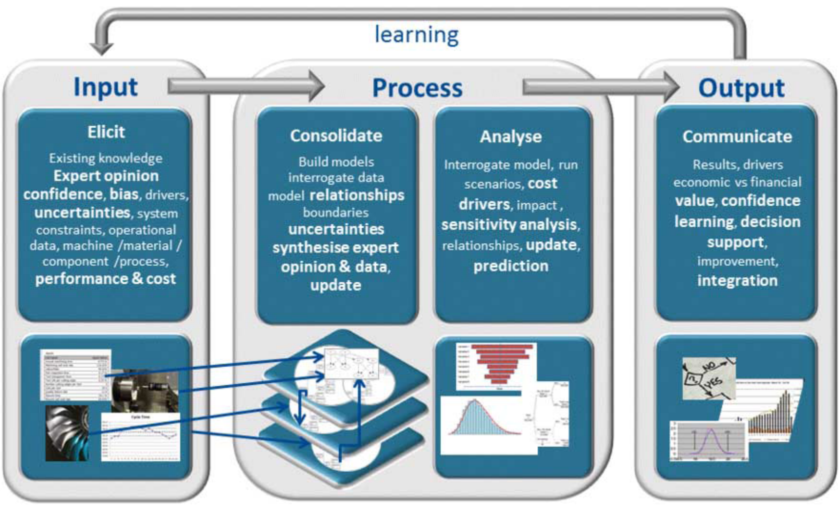

Figure 3. Conceptual framework for value-focussed decision making within advanced manufacturing R&D.

For the framework to be successful each of these aspects needs to be addressed. In particular the highlighted areas require further detailed investigation as there are currently no standardised solutions for use in this particular environment.

3.3. Capturing the requirements

The data requirements for populating the framework will depend on the system being modelled and the costing methodology chosen to represent the system. Qualitative and quantitative cost and performance data is required from existing R&D to populate the framework. Utility information is essential for metrics which will determine cost and quality decision boundaries [27]. A qualitative scale can be used to account for technology readiness, environmental impact, health and safety implications, and confidence and risk [28]. Capturing real time information relevant to the whole system will encourage information sharing and provides an environment for creating new knowledge [19].

3.4. Eliciting information

Information can be taken from existing databases or collected via interviews. Qualitative research literature gives insight into the most appropriate theories and methods to elicit and analyse the expert knowledge [29]. Semi-structured interviews provide a reliable method in this type of application [30].

The recommended process for the elicitation of expert opinion is shown in Table 3. The consensus among practitioners is that providing feedback can help to alleviate many issues with opinion bias from a group of experts, offering the 'opinion givers' an opportunity to revise their original estimate [31]–[33].

Table 3. Considerations for the elicitation of expert opinion (adapted from Kuhnert et al [34]).

Issues	Interpretation	Possible solution
Overconfidence	Overestimating accuracy of beliefs, underestimating uncertainty in a process.	Incorporating feedback mechanism
Conseratism	An expert understating their belief	Incorporating feedback mechanism
Representativeness	Opinions based on similar situations	Incorporating feedback mechanism
Availability	Basing a response on current information not on past events	Considerations of resoiurces. Availability of experts.
Anchoring and adjustment	Groups anchoring around initial estimates	Elicit the uncertainty around responses. For multiple experts, synthesise their responses.
Misunderstanding of conditional probabilities	Confusion of definition of conditional probabilities	Design around the available expert(s) Information from experts can be translated into prior probabilities.
Translation	Confusion in the translation of a response to alternative scale	Design around the available expert(s) Information from experts can be translated into prior probabilities.
Affect	Experts emotions	Examine the impact of priors. Where empirical data are available, run the models with and without the influence of informative priors.
Hindsight bias	Expert placing too much emphasis on past events	Examine the impact of priors. Where empirical data are available, run the models with and without the influence of informative priors.
Law of small numbers	Experts generalising their opinion	Examine the impact of priors. Where empirical data are available, run the models with and without the influence of informative priors.
Linguistic uncertainty	Misunderstanding the question	Clearly articulate the research question

3.5. Handling uncertainty

Uncertainty is complex and not necessarily resulting from a lack of knowledge – uncertainty can occur in situations with a lot of available information. Moreover the emergence of new information can both reduce and increase the level of uncertainty [35]. Uncertainty can be characterised according to a number of dimensions [36]:

1. Reliability (precision, credibility, uncertainty of the information quality)
2. Completeness (gaps, inconsistent definitions)
3. Accessibility (availability, rights of access, communication, format)
4. Relevance (usefulness in terms of decision making)
5. Representativeness (internal and external boundary issues, quantification)
6. Repeatability (variation in learning curves, consistency and reproducibility in data collection methods).

Uncertainty in research and development environments is the major source of risk and opportunity and causes many complications when developing a robust decision system, so a way to manage this uncertainty is critical [7], [13], [37]. A number of approaches for handling uncertainties in manufacturing knowledge exist, including simulation based approaches, Bayesian Networks (BN), Artificial Neural Networks (ANN), and Fuzzy systems. BN are provisionally favoured for the framework due to ease of use, mathematical rigour and suitability for system integration.

4. Conclusion

The need for a systematic value-driven decision framework for use in manufacturing research environments has been identified. A solution such as this does not currently exist, almost certainly due to the complexity of modelling the information within this type of environment.

This paper has argued that a synthesis of research methods is required. The framework is being developed through mixed methods research with a synthesis of modelling techniques. The framework draws on and extends existing research in the appreciation and challenges of the introduction of cost into early phases of development, the areas of knowledge and uncertainty management with in the context of applied manufacturing R&D, decision making through early phases of technology development. The framework is being operationalised with the decision makers and stakeholders to ensure that the scope and flexibility is anticipated and incorporated throughout its development. This research has the potential to be extended to other centres of a similar nature.

4.1. Limitations

A limitation of this work is that successful implementation of the framework demands that these research environments establish a standardised process for knowledge management. Whilst BN have been provisionally selected for uncertainty management, this decision has not been based on a comprehensive evaluation of all alternative methods could be performed; such testing is out of scope of the research aims.

4.2. Recommendations for further work

The next phase of this research is to operationalise and generalise the framework using two case studies. The first supports the introduction and roll out of a novel technology into an established process. The second is the advancement of the framework to select the most cost effective technologies from across the MCRL scale.

Mixed methods have been used to develop the research into a conceptual framework. The cycles of action research combined with the rigour of the Lean Six-Sigma [38] approach will enable the operationalisation of the framework through cycles of collaborative planning, acting, evaluating and developing to maximise the success of a value-focussed decision framework.

The chosen framework architecture is an object tree incorporating a cost versus capability (value) model, providing a hierarchical representation of the relationship between cost functions within a process. The synthesis of quantitative and qualitative knowledge as well as uncertainty modelling will be provided by Bayesian networks. Value functions will be employed for visualisation of trade-off alternatives.

Acknowledgements

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Digital Master as an Enabler for Industry 4.0

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Abstract. Regardless of whether it is a question of business or private lives, education, economy, public management and services or politics – the digital revolution covers all areas of our daily life. For enterprises, this inevitable move means in particular: New technologies and changes in customer behavior and demands throw established business processes off track, opening entirely new possibilities and opportunities. Nowadays, digitization is often mentioned in the same breath with other buzzwords such as Mobile and Cloud Computing, Big Data, Business Intelligence, Internet of Things, Industry 4.0 or 3D Printing. However, this does not go far enough – there are more important drivers pushing the digitization and digital transformation for business organizations. Globalization is one of them, for instance, but also social changes with a new generation of customers – the Digital Natives. In this paper we illuminate the background of the digital transformation, and introduce the term Digital Master or 3D Master for the industrial purpose. We highlight the specific needs and expectations of the automotive industry. In a case study the application of Digital Master is shown in the production planning and quality assurance, based on a practical approach.

Keywords. Digital Transformation, Engineering Collaboration, Digital Master, 3D Master, Intelligent Document, 3D PDF

Introduction

The digital transformation is affecting almost every aspect of our daily lives in business and leisure. Humans gradually are getting surrounded with digital devices. Nearly everyone is constantly connected to new technologies and uses services accessible online. Chats, shopping, banking, travellling, apps controlling field services, storage or maintenance as a service are just a few [1]. For people in the working age it is getting challenging to embrace work and live with old technology. Employees very often are technically better equipped at home than at working place. Young customers are often more technophile than technology vendors, thus enforcing transformation. The important fact frequently overlooked is however that these services are available only recently and are intended to improve at fast rising pace. Both, companies and private consumers are affected by this transition in a similar way [2]. The market share of products and services which are not yet affected by digital transformation dramatically decreases.

As far as the enterprise is concerned, a major challenge consists of constantly adjusting products and services to changing conditions and continuously optimizing

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supply chains by means of modern technologies. Such measures improve flexibility and agility significantly. The market player, who is the fastest in offering compelling solutions for customers, will be able to increase its market attractiveness and competitiveness sharply, keeping costs per unit low. Digital transformation drives every modern organization to align processes more customer-centric, improve service, act even more agile or enter new markets and develop new products [3][4][5].

Potentials for competitive advantages arise from technological opportunities and innovations linked to digital transformation (such as human-to-human, human-to-machine and machine-to-machine interaction). The relationship between the business organizations and its customer can essentially surge by new possibilities of interaction [3]. Not only marketing or sales departments, that traditionally had always geared toward communication and interaction with customers will have to adapt to new technological opportunities, the typical internal divisions such as research and development, production and logistics as well will have to [6].

Digital transformation reinvents business models and their related internal processes as well as the way corporate entities interact with their customers and partners. In fact, the possibilities of digital media are changing businesses dramatically – strategies, processes, structures, products, services and cultures are affected. People, machinery and resources can communicate directly and in real time. Rigid value chains are increasingly transformed into dynamic value networks, where the added value is created in an interaction of constantly communicating and flexible successive reacting units, largely organized by themselves [4].

Digital transformation is useful in service business in particular. In the area of rehabilitational healthcare, it has provided great opportunities for developing smart healthcare product-service systems. Nevertheless, challenges still exist to achieve secure and effective tele-healthcare services, which are aligned for future improvements as follows: self-learning and self-improvement, use of wearable devices, standardization, privacy and security [7]. In context of service selection and composition, different providers may offer the same service with different attributes and the importance of such attributes is subjective and varies in different contexts. Dynamicity in real-time service workflow interoperation creates complexity, in which changes of services' attributes is constant occeurence, and needs appropriate selection process [8]. Similarly, in the area of product life-cycle energy management (PLEM) the solution provides additional information for decision-making, enabling better service selection in service workflow. This however is still at infant stage, when it comes to application [9][10].

Novel technological approaches are heighting the industrial adaptation process. They serve the interaction between those involved in the company and their respective customers, to further accelerate the communication and information exchange in order to provide individualized services in real time. Thus, reducing the reaction time of companies to changes and replacing standardized products by individual, customized products is getting more and more relevant [11].

The structure of the paper is arranged as follows: Section 1 briefly introduces the levers of the digital transformation. Section 2 is focused on the concepts and applications in the automotive industry. The concluding remarks are presented in Section 3.

1. Enablers of the digital transformation

There are different approaches to rule the digital transformation. In a management oriented approach, authors have identified six elements that define the changing digital agenda: context, culture, capability, connection, contribution and communication [12]. In contrast to this approach, we follow the technological and organizational transformation which can be aligned with the general approach [1] to be applied for the product creation process.

Digital maturity is a combination of two separate but related dimensions. The first, digital intensity, is investment in technology-enabled initiatives to change how the company operates – its customer engagements, internal operations, and even business models. Firms maturing in the second dimension, transformation management intensity, are creating the leadership capabilities necessary to drive digital transformation in the organization. Transformation intensity consists of the vision to shape a new future, governance and engagement to steer the course, and IT/business relationships to implement technology-based change [13].

1.1. Four levers of the digital transformation

Among the enablers of the digital transformation in the industry are the Internet of Things, a high-quality broadband coverage and an increasing automation of production. These aspects facilitate a new market positioning and value propositions, by means of Industry 4.0, fourth-party logistics (4PL) or Predictive Maintenance. Not only one of the single technologies and propositions aforementioned is paving the way for disruptive developments, instead a combination of them can be the solution. After all, the added value often derives from the interoperability of previously independent systems and the connection of previously separate spheres [1]. Network-centric operation occurs when systems are linked or networked by a common infrastructure, share information across geographic borders, and dynamically reallocate resources based on operational needs [14]. Digitization accelerates the evolutionary process in the field of products and services. The digital transformation influences the industrial change upon four levers:

Digital data: Based on an automated acquisition, processing, analysis and sharing of digitized mass data better predictions and decision making in shorter time will be possible, (which will be further presented in the section 2) [15].

Automation: Interoperability of traditional technologies with autonomous, artificial, smart, pervasive systems yields the reduced error rate, the shorter time-to-market and the drastically reduced operating costs in Industry 4.0 approach [16].

Networking: High-quality broadband telecommunication facilitates networking across the value chain, allowing to synchronize supply chains, to shorten production times and to improve innovation cycles.

Digital customer integration: The (mobile) internet allows to acquire direct access to customers and to offer them complete transparency and completely new services via new intermediaries, preserving their privacy [17].

The crucial value levers do not lie in technology but in the correct interpretation of the data arising along the value creation chain [18]. Who is able to establish strategic control points along data collection and data analysis will profit the most from the next industrial revolution. Disruptive changes in various enterprises yield to tremendous opportunities, growth and profit.

Hence, entire value chains are digitally disrupted, that is, innovative companies move from existing business models in adjacent areas. Various SMEs recognize the digital transformation as crucial for their business model and their business strategy. The secret of success is to understand the rules of the digital market and to set strategic checkpoints faster than competitors. Mere online players are often much better positioned than traditional companies. So they are able to take advantage of inefficiences in traditional supply chains and transform them to their benefit [13].

1.2. Impact on the automotive industry

Disruptive shifts are expected in the automotive industry and logistics [19][20]. Driven by shared mobility, connectivity services, and feature upgrades, new business models could expand automotive revenue pools by about 30 percent, adding up to $1.5 trillion. Despite a shift toward shared mobility, vehicle unit sales will continue to grow, but likely at a lower rate of about 2 percent per year. Consumer mobility behavior is changing, leading to up to one out of ten cars sold in 2030 potentially being a shared vehicle and the subsequent rise of a market for fit-for-purpose mobility solutions. City type will replace country or region as the most relevant segmentation dimension that determines mobility behavior and, thus, the speed and scope of the automotive revolution. Electrified vehicles are becoming viable and competitive; however, the speed of their adoption will vary strongly at the local level. Within a more complex and diversified mobility-industry landscape, incumbent players will be forced to compete simultaneously on multiple fronts and cooperate with competitors. New market entrants are expected to target initially only specific, economically attractive segments and activities along the value chain before potentially exploring further fields. Once technological and regulatory issues have been resolved, up to 15 percent of new cars sold in 2030 could be fully autonomous [21].

The original equipment manufacturers (OEM) and their major suppliers already started the transformation process in the automotive industry having a number of major programs initiated, inter alia, new stage of interconnectivity by introduction of the comprehensive IP protocol in the vehicle. It embraces full communication functionality and facilitates enhanced infotainment, better safety, highly automated and autonomous driving, and enhanced parking capability (Figure 1) [22].

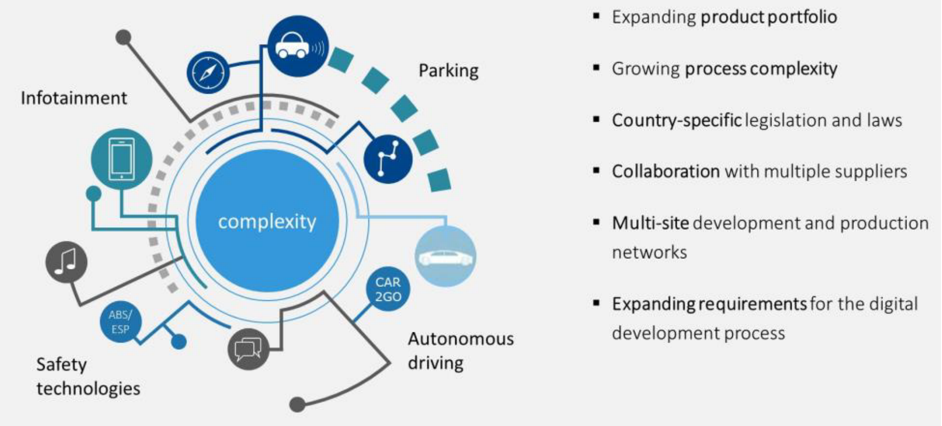

Figure 1. Digital Transformation at Daimler: Trends and Business Strategy [22].

New business models are seen in the expansion and complementation of the existing service portfolio, generating new potential for value creation and developing the business model from a product provider to a solution or service provider by adding a combination of intelligent services to the value chain [19][15]. Realizing this is empeded with massive hurdels: The services intended to be offered are already accessible from the driver's mobile devices.

Simplexity – which is a complementary relationship between complexity and simplicity – is going to become dominant and most powerful driver for optimization. For example, by reducing the number of variants, a reduction of the effort is to be expected. An isolated view is therefore usually not possible. In addition, the potential of differentiation or standardization changes depending on the level of the considered product structure.

The following questions are crucial for the success of digital transformation in the field of automotive industry [1][19][20][22]:

- Who will exploit the gap of the digital communication interface between the vehicle and the drivers or vehicle operators?
- Who owns the rights of the data that is created in and around the car, who is allowed to conduct their further use and processing? Which data will be publicly accesible? Who is allowed to make an offering and distribute it to the driver and the passengers?
- How does highly automated driving change the individual mobility of the consumers and their behavior when buying a car?

2. Use Case Digital Master (3D model-based Master)

The fundamental vision of integration in manufacturing is to achieve continuous flow of information in all lifecycle stages. This vision affects three layers as illustrated in Figure 2.

As described in section 1.1 integration is a widely requested "digital data" lever for digital transformation. It describes a product (born digital) holistically with (1) domain-specific application models for example, mechanical or simulation models. It demands cohesive communication in the (2) supply chain based on CAx data streams with partner, in joint ventures and across factory plants. It finally realizes (3) a fusion between up- and downstream in the entire lifecycle, where digital aspects of the product solely are used as engineering, manufacturing and service bridges.

Product lifecycle phases are affected differently by computerization. Physical products that were primarily mechanical are becoming more digitized. Systems Engineering has evolved to the prevailing development approach in Engineering. In Manufacturing, novel trends are now embraced by Industry 4.0. Internet of Things finally offers great potential in service by e.g. linking physical products with corresponding digital twins.

2.1. Requirements of downstream processes

Usually only certain data is necessary at sequences (gates) for assessment in downstream processes. Large and comprehensive functionalities, such as provided with modern CAx systems are usually not mandatory. In fact, the number of consumers of CAD data in extended enterprise is about a factor of 10 at least higher than users in engineering, where product data is created. The use of powerful CAx systems in development processes is certainly justified. Their use however in downstream processes such as purchase, production, assembly and quality assurance needs to be scrutinized in the course of an efficient product creation. For such reasons an additional model called Digital Master (Figure 3) is introduced.

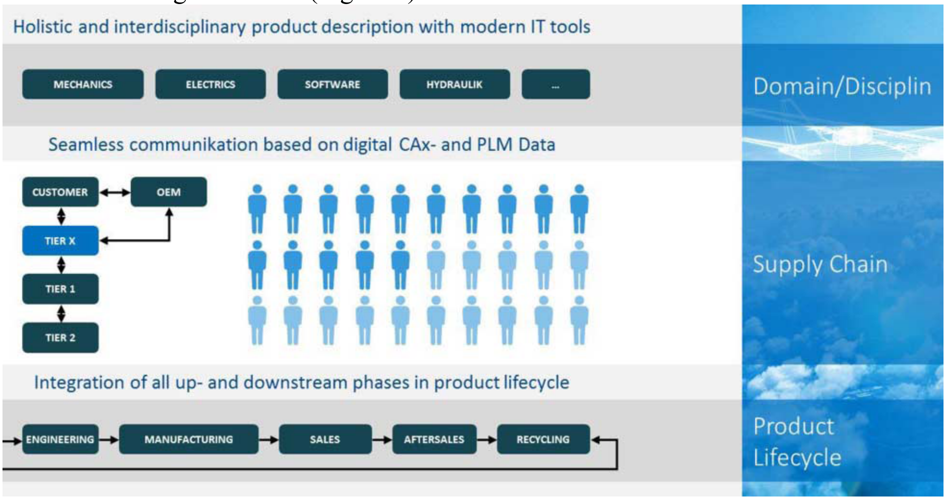

Figure 2. The integration vision in automotive industry.

The Digital Master enables the enterprise to collects, maintains and provides all system information at a dedicated point in time to all actors. Downstream process can access this information for their dedicated needs. Digital Master baselines allow traceability for all system elements.

Basically, the digital master represents a document-based approach in the development of complex products, which enables modern organization to share product data with downstream processes. Digital master models are a set of linked data records in self-contained document that provide a defined degree of maturity across the product lifecycle [24]. This concept is illustrated in **Figure 3** with a typical PLM context, emphasizing Systems Engineering, Industry 4.0 and Internet of Things as subsidiary concepts of PLM [23]. They enable the enterprise to handle and gain benefit from their existing Assets and IT landscape.

Digital Master models serve as a basis and major reference throughout the product development process allowing continuous verification of quality levels. Their process capability can be checked and slightly adjusted by corresponding quality check tools. Based on an integrated product data model, all relevant information can be stored in a self-contained document, managed and operated in conjunction with a suitable PLM integration. By creating a neutral interface, not only cost and effort can be reduced, but also the interoperability of systems, processes and data formats is improved.

Digital Master enables a holistic information integration and improved interoperability in globally distributed product development processes. It replaces the traditional drawing as technical documentation master, which can be derived thereof for information purpose only.

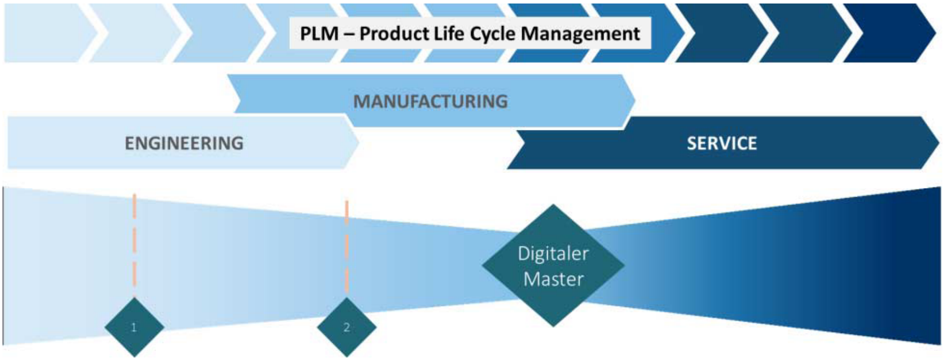

Figure 3. Emergence of the Digital Master [23].

An unambiguous semantic-rich representation of a complex spatial part with 3D model can be generated automatically as an instance of a Digital Master. Realizing this in the context of an extended entrerprise requires three fundamental aspects: integration, management and delivery of information to recipients.

Integration deals with various data segments used to contextually describe the overall product from its different application domains in a Digital Master document. As far as data formats are concerned, it includes CAx system-specific data formats used to natively describe 3D representation, technical drawings or PLM data as well as neutral formats (such as STEP, JT or PDF). These data are retrieved, classified and merged (sematically and contexttually linked) into a container by means of a converter tool. A distinction is made mainly between geometric representation, semantic-rich attributes and metadata as well as miscellaneous documents. Based on this, the data are assigned to a PDF, JT or STEP AP242 XML segment building the main parts of the Digital Master document.

Management provides methods and workflows for the creation of relevant baselines in dedicated time sequences by deriving all necessary data from a backend. A PDM integration provides crutial functions such as entity, privilege and workflow management. This allows a structured, centralized management of Digital Masters while taking into account the complete history of affected product data.

2.2. Usability of 3D master

The usability of the Digital Master based on neutral models spans the entire product lifecycle. The use of the standardized and in industry proven formats 3D PDF, STEP and JT simplifies the integration of information from various authoring systems. As a result, a continuous flow of information and a consistent use of models in all phases of the product lifecycle are achieved without media discontinuities. The concept of Digital Master models supports conventional tasks of the product development, such as requirement identification, design reviews and engineering change management. As for new developments 3D models are usually not available in early stages, rough dimensions of the building space can be defined. In this case, bounding boxes are used as placeholders for components and installation spaces in the Digital Master. Requirements can be added via semantic annotations in the Digital Master, this can also be conducted using mobile devices. In this way, the transparency is heavily improved. Each registered user can participate in this process.

Design reviews are performed in frequent repeatable cycles during the product development. Deriving the Digital Master from the PDM system allows to timely retrieve data on costs, materials and the degree of maturity of the product under development. This information can be visualized directly in the Digital Master using color coding and semantic annotations like PMI. Due to the fact that CAD neutral formats are used, the functionality of CAD viewers is sufficient for this purpose. This helps saving the costs of CAD licenses and eases the use of mobile devices. Defined interfaces enable the integration of 3D models into Office documents and 3D PDF documents. The greatest potential of the 3D master models is provided in the deployment of 3D models with meta-information for downstream processes. Digital Mock-ups (DMU) can't be easily replaced by Digital Master, but improved by the possible simplified data enrichment with metadata [25]. Furthermore, Digital Master enables the deployment of high-performance 3D models and assembly simulations.

In case of tolerancing, the main work usually starts in the mature phase of the product development and is later expanded during the production planning. Holistic view on the tolerances requires an early examination of reasons, assessment of impact and consequences of tolerances. This requirement could be fullfiled by Digital Master under certain circumstances. Such solution concept must resove the following challenges: CAD system dependency, easy translation into neutral formats, method compliance, cost effectiveness and availability of tolerancing know-how in early design phase [23]. That are the pre-requisites for deployment in an Industry 4.0 approach.

Digital Master provided in a certain frequence could yield the following benefits: single (real) master, digital availability, visualization, invest-friendly by standardization. In such way, Digital Master could evolve to an entry point for an automated dimensional quality control in Industry 4.0 systems which need the comprehensive information on environment (Figure 4).

A practical implementation lies on a general use of geometrical dimensioning and tolerances in 3D CAD system and a comprehensive support for the designer on 3D tolerancing. Due to the considerable complexity of such tolerance chains, which is hard to control by a human in a short time, the consistency of singular tolerances must be frequently checked by an appropriate check tool. After the desired status is achieved, CAD model must be translated into a lightweight format (3D PDF or JT). In case of structures, STEP AP 242 could be also used. Finally, such 3D lightweight model must be included into the Digital Master document which already contains the metadata extracted from the PDM system.

Figure 4. Model-Based Definition with GD&Ts inside the Digital Master Model [23].

2.3. Provisioning of Digital Master

The concept presented here encompasses the elaboration of Digital Master by using standardized and neutral formats, plus the related meta-information. Information from disparate authoring systems can be integrated and made available for use in the entire product lifecycle. The 3D PDF or JT segment facilitates the efficient visualization of 3D product data. Based on viewers, the use of mobile devices is possible. The STEP AP242 segment provides the XML schema to integrate the geometry and metadata. Geometry is embedded, the meta-information is stored in intelligent PDF templates. In an early phase of product development, the annotations from Digital Master could be automatically translated in a formalized requirement specification. The software connection to a PDM system enables proven functionality as elements and privileges management and integrates them into the digital masters. As part of this, also the multi-input converter tool to integrate the information from the various data sources is necessary and should be installed.

This concept significantly saves operational costs by reducing system-specific interfaces and improves the interoperability throughout the entire product lifecycle. The use of standardized neutral formats leads to a reduction in the number of CAD systems to be involved, whereby licensing costs are economized and staff access to information is facilitated. Furthermore, a plethora of software applications is already available for 3D PDF, STEP and JT. All these applications can be distinguished by user-friendly handling and low costs in comparison with CAD systems. The training expense drops dramatically. In the sum, the invest costs are also significantly reduced by implementing Digital Master.

3. Conclusions and Outlook

High interoperability makes an important contribution to engineering collaboration. Several formats made to that end successively deal with challenges of their time. Some of these such as STEP are highly verbose formats, which gradually encapsulate all information necessary to define a product, its manufacture, and lifecycle support. Others are focusing best on lightweight visualization use cases and endure better with increasing size and complexity of data.

Traditional formats like STEP and JT, though, are not capable of supporting the publishing activity in even broader fashion. New tendencies therefore are aiming at strengthening these individual formats through combination with complementary standards or by using document-based approaches. An expanded information model can manage this additional information for the Digital Master. However, in the era of lean and agile, seamless collaboration needs continuous planning.

Unlike STEP or JT, 3D PDF can serve multiple purposes and leverages 3D data downstream throughout the product lifecycle to create, distribute and manage ubiquitous, highly consumable, role-specific rich renditions. 3D PDF is a fundamentally different approach from traditional experience established in product development – it is an exceptionally proficient contextual aggregation of multi-domain and multi-disciplinary product data. The manufacturing community should embrace it as an addition and great improvement to current engineering collaboration standards [26]. All engineering components required for its descriptions are meanwhile published international standards.

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Part 11

Cost Engineering

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Transdisciplinary Engineering: Crossing Boundaries
M. Borsato et al. (Eds.)

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Aircraft Disposal and Recycle Cost Estimation

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Abstract. The present study develops a method for the sake of evaluating Disposal and Recycle (D&R) cost in view of the increasing demand in aircraft retirement. Firstly, a process model is extracted. The subordinated cost elements are also identified. Next, the cost aggregations based on the D&R process steps are discussed. Moreover, it proposes an economic indicator to support the determination of the aircraft D&R strategies. The indicator is used to evaluate the economic performance and to facilitate the trade-off studies among different D&R scenarios. This analysis is demonstrated on two aircraft types with two scenarios. In addition, sensitivity analysis evaluating the impact of the salvage value, residual value, D&R cost, and the learning factor is performed. It is found that the engine D&R possesses more economic gains than that of the aircraft. The salvage value and residual value are the main factors which influence the D&R economic performance.

Keywords. Cost analysis, aircraft disposal and recycle process, disposal and recycle economic indicator

Introduction

Within the current commercial aircraft service, more than 8500 aircraft have been retired and it is expected that around 6600 aircraft would be retired in a decade [1][2]. This leads to the development of aircraft Disposal and Recycle (D&R), see Figure 1. The D&R process is related to the original design via the material choice and the component recyclability and recoverability [3]. It is associated with the aircraft status due to the operating and maintenance condition before parking. It is also linked with the engineering processes such as dismantling, sorting, and component management. Based on the aforementioned properties, it clearly indicates a transdisciplinary feature within the D&R process and the corresponding analysis [4].

Figure 1. Aircraft disposal and recycle (picture source: AELS website [5]).

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Significant savings can be identified by comparing the labour, material, and energy consumptions for two processes: the D&R process of recycling an old component or produce recovered materials, and the manufacturing process of producing a new component or virgin materials. For example, it was found that the cost of manufacturing the virgin carbon fibre is around 15-30 US $/lb in 2011, while only 8-12 US $/lb is needed via recycling [6]. Moreover, recycling the aluminium material from scrap can save up to 95% energy, and producing recovered aluminium metals can reduce 39% energy consumption [7][8]. This is the main reason for the D&R process to stay competitive in the aviation market. However, due to the small industry size of the aircraft dismantling and recycling, few studies have been conducted on analysing the D&R process and its economic performance. The aircraft economics, the company economics, and the global economics often restrict the aircraft end-of-life solutions [3]. Along with the growing of the industry, it becomes necessary to conduct those analyses quantitatively. Literature shows that the aircraft disposal cost is around 10% of the purchase price or 1% of the total life cycle cost [9][10]. However, those rough estimates cannot improve the D&R process economic performance. Recently, research related to the disassembly sequence and its efficiency have been conducted by Dewhurst [11], Johansson [12], and Germani et al. [13] to support the product development, while a systematic approach is still needed.

The cost analysis is potentially an effective means of evaluating the commercial aircraft D&R process development, since it connects the product, process and cost throughout each process step and provides stakeholders with the economic estimates by aggregating the costs of the process steps. By considering the transdisciplinary analysis approach [14][15], end-of-life solutions of the commercial aircraft can be determined through a dynamic and adaptive system where diverse disciplines crossing boundaries can be handled.

1. Aircraft disposal and recycle process analysis

A generalised D&R process is shown in **Figure 2**. A process block represents a main process step or a group of sub-process steps. Some sub-process steps are listed in the brackets within each process block. The D&R process is determined based on the status of the aircraft and the customer requirements specifically for the recycle and reuse [3]. Some are stored in the aircraft boneyard, some are reconditioned and repainted for exhibitions, some are processed as recovered materials to be supplied to other products.

During the storing phase, the aircraft is transported, parked with or without performing maintenance activities. Whether the maintenance is necessary mainly depends on the aircraft current condition and its future usage. After deciding not to park the retired aircraft, it can either be reconditioned and recertified for resale and reused as a whole product, or be disposed of through a series of D&R process steps. When disposing an aircraft, it is firstly disassembled to get all the valuable components removed in order to be reused on the other aircraft or for alternative reuse. For a component to be reused on the other aircraft and engine, the component needs to be firstly recertified. If it is used alternatively such as for product exhibition, it often needs to be reconditioned. The airframe is dismantled by removing and scrapping hazardous materials, and it is cutted and shredded into pieces. Material sorting and separating are often performed manually right after the dismantling process. Depending on the material properties, the scrapped materials can be used for the secondary recycling, which is distinguished from the primary recycling for materials scrapped during the aircraft manufacturing processes. In general, the metal, glass, plastic, and composite parts are sorted out. Based on their sizes, different materials are supplied for respective recycling processes. Metal parts are firstly grouped by sizes. Then they are melted to be reformed to new parts. The composite parts such as Carbon Fibre Reinforced Plastic materials can be decomposed and the pure carbon fibres can be extracted. Those carbon fibres can then be reused as recovered materials for new components, which are often non-structural parts inside the aircraft or parts for automotive components and for electronic instruments. Two types of secondary recycling processes are divided in terms of the quality of the recovered materials. One is recycled without losing the material quality; the other is recycled containing paint/glue or recycled by the immature recycling techniques, lower quality materials are obtained accordingly, also called down-cycling. If the material cannot be recycled but can be burnt as wastes, the burning process will then converts the burning energy to heat or electricity, so-called energy recovery. In an ecological hierarchy, the last level of the end-of-life solution would be landfilling when the part/component material cannot be reused, recycled or used for energy recovery.

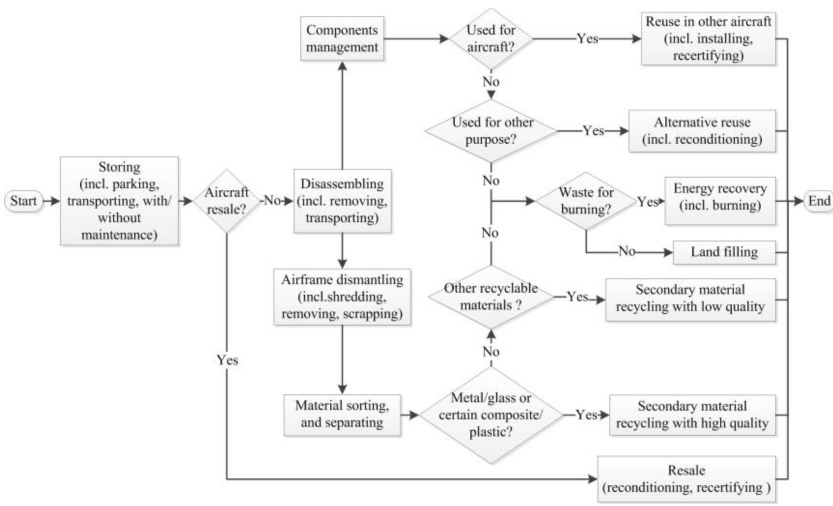

Figure 2. Aircraft disposal and recycle process model (adapted from [3] and [16]).

Taking a B737 D&R project as an example, the following process flow can be constructed: The aircraft is purchased and transported to the disposal site; then the systems such as the air conditioning, autoflight, and electrical power are removed, the engine and landing gear are also removed; some systems and engine parts are reconditioned, recertified, and reused for the other aircraft; the landing gear is scrapped; the airframe is shredded and the materials are sorted to be further recycled as recovered material. For a DC-9 project, the nose section, the engine cowl, and the landing gear are planned to be used for exhibition. The following process can be proposed: The aircraft is firstly purchased and transported to the disposal site; the engine cowl and the landing gear are removed, reconditioned, painted and transported to the exhibition site; then a D&R process similar to the previous one is conducted for the rest of the aircraft. Those two examples are constructed by referencing two D&R projects conducted by AELS [5], while the constructed process steps are conceptual for demonstration purpose and not necessarily the same as they were conducted.

2. Disposal and recycle cost estimation method and the economic indicator

The cost estimation method is developed based on the integration of the product, the D&R process, and the cost properties. According to the aircraft material usage and the customer requirements, the D&R process can be planned. The D&R process plan is generated based on the D&R process model and the rules embedded in the model. For example, if it is an engine part to be reused in other aircraft, the engine should be removed, repaired and recertified for reuse. Those process steps are set up sequentially for this specific case. When the engineering rules are sufficiently extracted, the process plan can be automatically generated. The total cost is formulated by summing up the costs of all process steps in a D&R process plan, see Eq.(1). The generalized cost function contains all possible process steps. When sub-process steps are subordinated to a main process step, the cost function can be further detailed. When only some of the process steps are conducted in a D&R process, only the costs of those steps count, others default as zero.

Next, the D&R cost can be obtained by aggregating each cost element defined in the Cost Breakdown Structure (CBS) for every D&R process step. During the cost aggregation, Cost Estimation Relationships (CER) and economic rates are utilised for calculations. The CBS of the D&R process step cost is shown in Figure 3. The total cost of a D&R project includes the labour, material, energy consumptions for each D&R process steps, the facility, tooling & equipment costs used to facilitate the D&R operations, the residual value related ownership cost, and the miscellaneous cost such as the overhead cost, shown in Eq. (2).

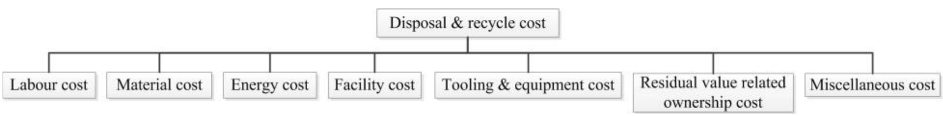

Figure 3. Disposal and recycle cost breakdown structures.

The cost estimation aggregates all cost elements for each D&R process step, see Eq. (3). The cost aggregations are shown explicitly through the labour, material, and energy costs. Since those three cost elements are directly linked to the process steps. Other cost elements, such as facility, tooling&equipment costs, are mostly one-time investments, which can either be estimated as a lump sum or be distributed over each D&R process steps to be aggregated later. The process step denoted as k refers to the D&R operations such as storing, maintenance, transportation, disassembly, dismantle, removing, sorting, reconditioning, scrapping, and recertification [17]. A process step contains a group of sub-process steps. For each step, all cost elements should be considered. For example, the storage of the aircraft contains the transportation of the aircraft, the maintenance activities before parking, and the aircraft parking process (see Figure 2). The aircraft transportation involves the costs of the crew (labour) and fuel (material); the maintenance cost contains the cost of maintenance mechanics and the cost of material used for repair; the parking cost includes the parking charge and maintenance labour/material consumptions during parking. Besides, there is also a residual value related cost element of the yearly investment for the disposal company to keep the aircraft for the moment based on its residual value. The aircraft residual value refers to the estimated aircraft price once it is retired. Eq.(4) shows the approximated residual-value-related cost, which is a portion of the aircraft residual value multiplies the number of years required for conducting the D&R process. In general, the residual value is around 10% of the aircraft price [18]. The yearly investment cost is approximately 5% of the aircraft residual value [16].

$$\begin{aligned} C_{D\&R} &= \sum_k C_{D\&R,k} = C_{D\&R,storing} + C_{D\&R,component\_managment} + C_{D\&R,disassembly} \\ &+ C_{D\&R,airframe\_dismantling} + C_{D\&R,material\_sorting\&seperating} + C_{D\&R,reuse} \\ &+ C_{D\&R,alternative\_reuse} + C_{D\&R,energy\_recovery} + C_{D\&R,land\_filling} \\ &+ C_{D\&R,recycling\_lq} + C_{D\&R,recycling\_hq} + C_{D\&R,resale} \end{aligned} \quad (1)$$

$$\begin{aligned} C_{D\&R,k} &= C_{D\&R,k,labour} + C_{D\&R,k,material} + C_{D\&R,k,engergy} + C_{D\&R,k,facility} \\ &+ C_{D\&R,k,tooling\&equipment} + C_{D\&R,k,residual-related} + C_{D\&R,k,miscellaneous} \end{aligned} \quad (2)$$

$$\begin{aligned} C_{D\&R} &= \sum_k C_{D\&R,k,labour} + \sum_k C_{D\&R,k,material} + \sum_k C_{D\&R,k,engergy} + C_{D\&R,facility} \\ &+ C_{D\&R,tooling\&equipment} + C_{D\&R,residual} + C_{D\&R,miscellaneous} \end{aligned} \quad (3)$$

$$C_{D\&R,residual} = r_{yearly\_residual} P_{residual} (1+I)^{FY-FY_0} n_{year} \quad (4)$$

where, $C_{D\&R}$ is the D&R cost. Different cost elements composing the D&R cost are also denoted. $C_{D\&R,residual\text{-}related}$ is the residual-value-related cost invested by the disposal company based on the yearly residual rate ($r_{yearly\_residual}$), aircraft residual value ($P_{residual}$) and years of keeping the aircraft (n_{year}). The yearly residual rate is assumed as 5% [16]. I is the inflation factor. When the cost is considered in the fiscal year FY other than the reference year FY_0, the influence of the inflation should be incorporated.

Furthermore, the salvage cost ($C_{salvage}$), extracted from the resale of the recycled components and materials, are considered as the value of the aircraft or aircraft component including the valorisation after the D&R process. Note that in this research, the salvage cost concept is interchangeable with the salvage value, which is defined as the actual or estimated resale price of an aircraft, engine or component based on the value of marketable parts that could be salvaged for re-use on other aircraft or engine or for other reusable purposes according to the International Society of Transport Aircraft Trading (ISTAT) [19]. Similar terms such as the part harvested value or the component market value are also utilised in the literature [2][16]. In order to provide a measure of the economic performance of the D&R process, a D&R economic indicator ($I_{D\&R}$) is proposed, see Eq.(5). It refers to the ratio between the valorisation and residual value of the aircraft. When $I_{D\&R} < 0$, the D&R process is economically inefficient cdxsince there is a lost during the D&R operations. When $0 < I_{D\&R} \le 1$, the anticipated valorisation recovers part of the aircraft residual value via the D&R process cost. Therefore, it indicates that the process cannot fully harvest the residual value of the aircraft. When $I_{D\&R} \ge 1$, the D&R process recovers the aircraft residual value or even larger. The process is profitable. In general, the bigger the D&R economic indicator is obtained, the better the D&R solution would be.

$$I_{D\&R} = \frac{C_{salvage} - C_{D\&R}}{P_{residual}(1+I)^{FY-FY_0}} \quad (5)$$

Moreover, when a disposal company repetitively performs similar D&R process steps for aircraft of the same type, the D&R process would gradually become mature. The labour cost based on the labour hour consumption will be reduced. This is analogous to the learning effect considered in the production process: when the number of aircraft or aircraft components to be produced is doubled, the labour cost of manufacturing one more product would get reduced [9]. It is often characterized as a logarithmic format. Similarly, by applying the learning effect to the D&R process, the D&R economic indicator including the learning effect for the Q^{th} aircraft can be expressed as Eq.(6). In order to capture and emphasise the influence of the learning effect, only the labour cost is considered to represent the D&R consumption, where Q_0 is the initial quantity of the aircraft which has gone through the same series of D&R operations, $r_{learning}$ stands for the learning factor.

$$I_{D\&R,learning} = \frac{C_{salvage} - \left(\frac{Q}{Q_0}\right)^{\frac{\log r_{learning}}{\log 2}} C_{D\&R,labour}}{P_{residual}(1+I)^{FY-FY_0}} \tag{6}$$

Since the cost estimation method and the proposed economic indicator are linked with the product properties and the disposal and recycle process steps, it can be implemented by combing the proposed functional capabilities with the current CAD/CAE software applications. In addition, the proposed method can also be integrated with available cost analysis tools.

3. Cost analysis and results

In this section, the analysis is conducted based on the data collected by the team SAI from three categories of responses from survey investigation [2]. The average cost of dismantling an airframe or engine classified by aircraft types can be seen from Table 1 and Table 2 [2]. The aircraft average residual value is assumed 10% of the aircraft average price, see Table 3. The D&R economic indicators can then be obtained (Table 4). Note that the term 'aircraft' shown in Table 1 to Table 4 refers only the airframe and systems without engines. For aircraft disposal and recycle, the R&D cost indicator of the regional jets is shown the highest value, while that of the wide body aircraft is low. This is because a regional jet often has a relatively low purchase cost but a high salvage value. For an engine dismantling process, the D&R activities for those three aircraft types are all profitable. This can be explained by the large salvage values of all recovered engines. A regional jet engine obtains the highest D&R cost factor, and it is followed by narrow body aircraft, then by wide body aircraft. This is similar to the trend shown by the D&R economic indicator for aircraft (without engines). Comparing the engine and the aircraft for all aircraft types, the economic performance of the engine D&R process is more profitable than that of the aircraft D&R.

Table 1. Average dismantle cost of an aircraft/engine (2014$) [2].

	Narrow body	Wide body	Regional jet
Aircraft	$74,000	$102,000	$49,000
Engines	$24,000	$33,000	$23,000

Table 2. Average value of parts harvested from an aircraft/engine (2014$) [2].

	Narrow body	Wide body	Regional jet
Aircraft	$1.5 million	$2.5 million	$2.0 million
Engines	$2.7 million	$3.7 million	$1.5 million

Table 3. Average aircraft price and residual value (2014$) (data resource for aircraft price [20][21][22]).

	Narrow body	Wide body	Regional jet
Aircraft price(total)	$87million	$ 263 million	$25 million
Engine price	2x$10million	2x$20million	2x$3million
Total residual value	$8.7million	$ 26.3 million	$2.5 million
Aircraft residual	$6.7million	$22.3million	$1.9million
Engine residual	2x$1million	2x$2million	2x$0.3million

Table 4. Average values of the disposal and recycle cost indicator.

	Narrow body	Wide body	Regional jet
Aircraft	0.21	0.11	1.03
Engines	2.68	1.83	4.92

In more detail, by taking the estimated costs of D&R process for a B737-300 project and a B747-400 project, a list of cost items are summarised in Table 5 and Table 6. The data resources come from the research conducted by van Heerden in 2005[16]. The B737-300 was built in 1986 with CFM56-3B-1 engines, and it was priced $133 million. The B747 was built in 1989 with CF6-80 engines, and the price was $59 million. Two D&R scenarios were considered: the disassembly and dismantle scenario and the resale scenario. The former refers to a disassembly and dismantle process immediately after the aircraft reaches the end of its life; the latter is to resale the aircraft after parking the retired aircraft for one year. The costs in Euro (€) are all converted to dollar ($) via the euro-dollar conversion rate in the fiscal year 2005, *i.e.*, €1=$1.18. Note that there are labour, material, and energy consumptions in transportation, maintenance, and project management processes, while they are not separated specifically for each process step due to limited data availability.

The D&R economic indicators for B737-300 and B747-400 evaluated for both scenarios are shown in Table 8. Obviously, the B737-300 disassembly and dismantle would fully recover the aircraft residual value with extra benefit, and the B747-400 would make a profit from the resale solution. Decisions on disassembly& dismantle or resale can be made through the comparison of the D&R economic indicators for different D&R scenarios.

Along with the increase of similar D&R operations for more aircraft, it is intended to capture the labour cost reduction using the learning effect incorporated D&R economic indicator. Assuming the evaluation is the initial D&R process for the first aircraft of both product types. The estimations for the *1st*, *30th*, and *300th* D&R operations using 80% learning factor are conducted for B737-300 and B747-400 respectively. Note that the learning effect is applied to the labour cost element within the disassembly and dismantle scenario; while for the resale scenario, the learning effect is incorporated in the maintenance cost element in this research. The results are illustrated in Table 8. It can be seen that the impact induced by the learning effect on the D&R process is reflected via the D&R economic indicator. However, since the labour cost consumed is much less than the salvage value gained, the influence of the learning effect on the D&R economic performance is little. The differences between the D&R processes for the 1st and 30th operations are slightly bigger than that between the 30th and 300th D&R practices.

Table 5. Disposal and recycle costs for B737-300 and B747-400 disposal and recycle projects (2005$) [16].

D&R process cost elements ($)		Disassembly and dismantle		Resale	
		B737-300	B747-400	B737-300	B747-400
Storing	Transport	-	-	177000	177000
	Parking (yearly)	-	-	3600	5400
	Maintenance (yearly)	-	-	159300	159300
	Investment (yearly)	-	-	135700	666700
Disassembly & dismantle	Labour	31860	123900	-	-
	Material	5900	11800	-	-
	Transport	3540	11800	-	-
	Scrap	2360	7080	-	-
	Equipment	17700	35400		
	Project management	7080	14160	-	-
	Overhead	2950	5900	-	-
Total D&R ($C_{D\&R}$)		71390	210040	475600	1.0e6

Table 6. Salvage values for B737-300 and B747-400 disposal and recycle projects (2005$) [16].

D&R process cost elements ($)	Disassembly and dismantle		Resale	
	B737-300	B747-400	B737-300	B747-400
Salvage value	3.2e6	13.2e6	3.0e6	17.1e6
Aircraft residual value	2.7e6	13.3e6	2.7e6	13.3e6

Table 7. Disposal and recycle economic indicators for B737-300 and B747-400 disposal and recycle project.

D&R economic indicator	Disassembly and dismantle		Resale	
	B737-300	B747-400	B737-300	B747-400
$I_{D\&R}$	1.16	0.98	0.94	1.21

Table 8. Disposal and recycle economic indicators for B737-300 and B747-400 disposal and recycle project.

D&R economic indicator	Disassembly and dismantle		Resale	
	B737-300	B747-400	B737-300	B747-400
$I_{D\&R,learning}$ (Q=1)	1.17	0.98	1.05	1.27
$I_{D\&R\_learning}$ (Q=30)	1.18	0.99	1.09	1.28
$I_{D\&R\_learning}$ (Q=300)	1.18	0.99	1.10	1.28

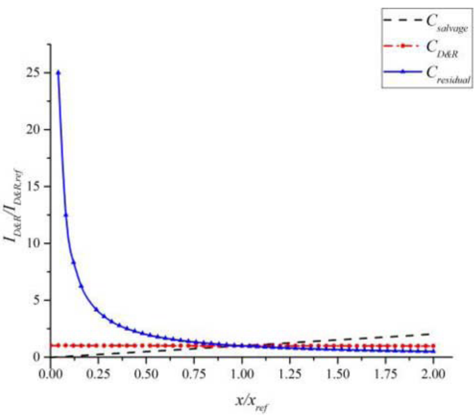

Figure 4. Sensitivity analysis for D&R cost indicator.

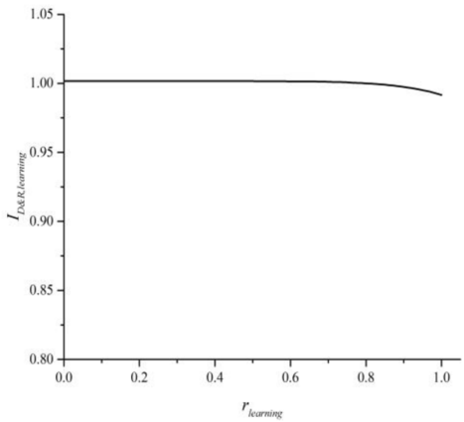

Figure 5. Influence of the learning factor to D&R cost indicator.

Additionally, in order to identify the impact of the driving factors for the D&R economic indicator, sensitivity analysis is exemplified for the B737-300 case. By applying $\pm 100\%$ margins to one of the parameters influencing the D&R economic indicator while fixing the other parameters, the corresponding changes reflected via the cost indicator are shown in Figure 4. The horizontal axis represents the change of the driving parameters, normalised by x/x_{ref}. It can be seen that the changes in the residual cost and the salvage cost are the main drivers of the variation of the D&R economic indicator. When the residual cost is reduced to be close to zero, the D&R economic indicator is raised drastically, which determines the economic performance of the D&R process. When the residual cost doubles, the D&R economic indicator gets halved. Increasing the salvage cost results in a steady increase of the D&R economic indicator. The increase of the D&R cost will slightly reduce the D&R economic indicator. Moreover, when varying the learning factor from 0 to 100%, the D&R economic indicator decreases within the range from 1.05 to 0.95, see **Figure 5**. It indicates that the slower the D&R process tends to mature, the lower the benefit would be obtained. Whilst the influence of the learning effect on the D&R economic performance is minor.

4. Conclusions

The present study proposed a D&R cost estimation method by means of integrating the product, process and cost properties. An economic indicator for the D&R process is also proposed, and it can be used to measure the overall performance of the D&R solution. Furthermore, such indicator can support the decision making, such as the disassembly and dismantle decision or the storing decision, within the aircraft D&R phase. It is found that the engine D&R possesses more economic gains than aircraft D&R. Additionally, the influence of the learning effect on the D&R economic indicator is studied. Results showed that the learning factor slightly impacts on the D&R economic indicator. This agrees with the sensitivity analysis, i.e., salvage value and residual value are the main factors which influence the D&R economic performance. The D&R cost has less influence on the economic performance of the D&R process.

Due to the fact that the salvage and residual values have significant influence in determining the D&R strategy, the methods that evaluate those two values need to be further investigated. Note that not all the cost elements are considered in this analysis, it might have reduced the impact of the D&R cost on the D&R economic indicator. It is therefore recommended to use cost parameters for each process step. Therefore, the cost drivers can be identified to support the development of the exact relationships between the parameters and the corresponding cost element. Other cost elements such as energy cost, facility cost, and tooling & equipment costs still need to be considered thoroughly in the future research.

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Manufacturability Analysis for Welding – A Case Study Using Howtomation© Suite

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Abstract. This paper is a summary of master thesis written in the fall of 2015 in the department of Product Development in Jonkoping University in Sweden as a part of a research project with focus on the implementation and management of systems for design automation and design for manufacturing. It includes an implementation with the aim of enhancing a system currently in operation at an aerospace supplier. The system is used for multi-objective design analysis in the early phases of product development. The analysis involves both the performance of the jet engines components as well as their manufacturability. The work is focused on the weldability assessment, based on available weld methods and the weld capabilities of the company. A number of rules for analysing the weldability are proposed. To keep this knowledge transparent, traceable and updatable it is managed by a novel software called Howtomation© Suite which is a forward chaining inferencing engine. The proposed framework enables a weldability index and welding cost guide to be derived, helping the designers choose appropriate weld method in early design stages.

Keywords. Design Automation, Knowledge Based Systems, Engineer to Order, Knowledge Base, Knowledge Object, Manufacturability Analysis, Manufacturing cost Analysis.

Introduction

According to S. K. Gupta *et al*. [1], Manufacturability analysis means evaluating the manufacturability of a proposed design with a given set of available manufacturing operations. Welding is one of the most commonly used joining technics. It is important to evaluate manufacturing feasibility of weld components during early design stages to avoid costly redesign and development delays [2]. One of the common requirements for customized products such as aerospace engineer-to-order (ETO) products is that the product designers have to consider a broad range of new design solutions [3]. The concepts of concurrent engineering (CE) allows the designers to make a wide variety of considerations such as manufacturability, assembly sequence, etc. during early stages of a product development process [2]. Design Automation, Knowledge based engineering, Design for Manufacturing (DfM) [4][5] are some of the techniques used in the manufacturing industry to meet the requirement in terms of product customization, product development time, manufacturability evaluation, cost estimation etc. The realization of individually engineered products can be made possible by the adoption of an automated engineer-to-order (ETO) [6] approach for quotation, development, and the production preparation processes [7][8][9][10]. The concepts of DfM allows the designer to consider manufacturing aspects such as materials selection and weld

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methods, weld sequence, assembly methods, necessary tools and fixtures for assembly, testing methods, etc. for the development of a product. The framework allows, up to 70% of a product's manufacturing cost to be estimated at the design stages [11]. It is important to have the ability to estimate the manufacturing cost of a component given its customer specification.

After doing interviews with the aircraft component manufacturer, it was understood that component manufacturing feasibility is also important, apart from the component functionality. Manufacturing feasibility analysis is required to avoid redesigns, reduce manufacturability cost and mainly to reduce part development time. The aerospace manufacturer is in the process of creating an automated tool that can assess the manufacturing feasibility of a component using existing product and process knowledge. The results of that investigation must enable the recognition of manufacturing difficulties and suggest methods suitable to manufacture and also determine an approximate manufacturing cost in the early design stages. The primary objective of this research work [12] is to develop an automated system which can perform a quick assessment of how well suited for welding a particular design is. This system will employ available industrial knowledge and give suggestions to the designers on how to improve the weldability of the design. It will also approximate the welding cost of that design. This is important in ETO companies to quickly go from the customer requirement specification to a quotation with most the competitive pricing.

1. Literature Review

Researchers have made some efforts to develop an automated computer software for evaluating manufacturability and to make cost estimations for welded components. Examples include Maropoulos *et al.* [13]. They made an attempt with a software named as "CAPABLE". It is a welding analysis software based on feature recognition technology. Yongjin Kwon *et al.* [2] have done similar work with the Sheet Metal Welding Advisor (SMWA) using customized C++ codes. The problem to use these developed techniques are knowledge transparency, details traceability and system upgradability. These are some essential maintainability aspects of a software tool for use in an industrial environment over a considerable length of time. The term transparency is a condition that all functions of a software must be disclosed to users [14]. The term traceability means that the user can find the version and amendment details of the current evaluation procedure including the references of the evaluation results. The term upgradability refers to the possibility to improve the existing system with a minimum of effort.

There are some commercial software's such as DFMPro [15] which is capable of evaluating the manufacturability of a design from its CAD model. DFMPro is also a ruled based analysis system which can evaluate the manufacturability of a design with a set of defined rules. The rules are maintainable and upgradable. The disadvantage with DFMPro is that the standard version if the system is not capable of weld evaluation for the time being.

Liu HongJun *et al* [16] have developed a method to evaluate manufacturability of an Aero-engine blade. The method is based on production rules and constraint-based machinability evaluation techniques. Kashid *et al.* [17]have developed an expert system for doing manufacturability assessment and process planning of sheet metal parts based on a production rule-based expert system approach. Rule-based analysis and constraint-based evaluation techniques have been utilized in this research work to develop an automated Weldability analysis system.

Vishal Naranje *et al*. [18] have developed a system for checking manufacturability, based on knowledge based system (KBS). Technical knowledge had been acquired from different sources of knowledge acquisition and framed in the form of production rules of 'IF-THEN' variety and then coded using AutoLISP language. Similar logic has been applied to this development work to make constraint-based weld evaluation with MS-Excel environment.

Jose M. Sanchez *et al.* [19] has developed a microcomputer-based Design Producibility Rating Tool (DPRT) to measure the producibility of simple metal components. The index has been derived from different design, material and manufacturing factors related to the level of design production difficulty. Weldability index has been introduced here with similar concepts to rank the weld methods for selecting most feasible method to a weld joint.

Joel Johansson, one of the co-authors of this paper has developed an automation software called as Howtomation©. It is a software developed with .net application. He has applied the Howtomation© suite to automate the heated runner systems for injection moulding of plastic material [7]. In addition to managing knowledge, it also has the capability of transferring information from one application to another. Examples include the CATIA, MS-Excel, MathCAD and Solidworks environments. The information transfer is realized by using ‘Knowledge objects’ and ‘Parameters’ objects. It acts as an inference engine to the developed weldability analysis system and making it possible to automate the entire process.

The producibility of fabricated Aero engine parts has been investigated by [20][21][22]. The authors have investigated how producibility aspects can be brought upstream, making the designs more suitable for manufacture by fabrication. In this paper a subset of this, namely the welding producibility is in focus

2. Weldability analysis system

The approach employed for development of weldability analysis system is similar to the one described by Shukor *et al.* [23]. The Manufacturability Assessment System (MAS) is a three step analysis system, which evaluate the weldability of a design from its CAD model with the available knowledge of the weld methods of the company. The basic approach of weldability analysis is shown in Figure 1. The details of the various subsystems shown in the Figure 1 will be explained later in this section. Component material and geometry details can be extracted from the proposed design’s CAD model with a *Details extraction system*. The weldability will be analysed with constraint-based *Weldability evaluation system* based on defined weldability rules which are similar to the Vishal Naranje’s [18] production rules with 'IF-THEN' logic. A *weld method’s knowledge base* can be developed with available weld methods and descriptions of the capabilities of an individual weld method. Here presented as weld-process data sheets for each weld method. The *Execution system* can do the weldability analysis with the developed rules. The developed weldability analysis system also enables the calculation of weldability of a design based on weld difficulty and presented as *Weldability Index (WI).* The output part consists of a *Result’s post processing system*, in which results from the analysis system will be summarised and the estimated cost to perform the welding operations will be presented.

2.1. Weldability Index

Weldability index is an index value which defines the weldability of a joint for a chosen weld method. Determining the weldability index is one way to rank all feasible weld methods to a weld joint. The weldability index (WI) refers to the level of difficulty of the weld. This method is an improved version of the CIM systems Industrial Automation company (Texas, USA) Producibility Rating tool called DPRT. During the weld evaluation process, the level of difficulty will be identified based on the details received through the design parameters, and will be rated based on set of standards defined in the weld method's knowledge base. The difficulty will be rated between 0.01 to1.00. But, if the criteria are not suitable to weld then the difficulty will be infinite. For all influencing factors the difficulty values will be averaged and an overall difficulty will be determined. Subtracting the overall difficulty from one, the weldability index will be determined. The result of this evaluation defines weld feasibility in terms of WI. In case of manufacturing conflicts between the design and welding, WI value becomes negative which indicates as infeasibility. The calculation procedure has been explained by following three steps:

1. Define difficulty level (DL) to each influencing factor
2. Calculate Difficulty Index (DI)

$$DI = \frac{\sum_{i=1}^{i=n} DL_i}{n}, \quad n = no.of\ influencing\ \ factors \tag{1}$$

3. Calculate Weldability Index (WI)

$$WI = 1 - DI \tag{2}$$

2.2. Cost modelling

The welding cost will be estimated based on chosen weld method, joint filler material (based on component material), length of weld, number of weld runs and the average weld speed of a chosen weld method. Different costing technics are available and used by the individual industry. Marginal costing techniques has been used for this work in which all the costs, related to a weld method are allocated to the cost heads. These cost heads are divided into two groups; one is 'fixed cost' and the others is 'variable cost'. Fixed cost is the cost paid by a company to keep the weld facility but is not dependent on the level of utilisation of the equipment. A suitable depreciation method can be used to allocate the fixed cost part to the weld cost per unit length. Variable cost is the cost that varies with equipment utilisation per unit weld length. Weld cost per unit length can be identified by adding the fixed cost and the variable cost. Furthermore, in the case of jigs and fixtures, common jigs and fixtures will be depreciated and will be add to the cost. But the cost of exclusive jigs and fixtures have to be added separately. The requirement of exclusive jigs and fixtures will be identified based on weldability failures in terms of tool accessibility.

2.3. Details extraction system

Different techniques can be used to extract geometry and material details from the CAD model. Feature recognition technique is used in some commercial packages [15].

Parameters tagging is another way to extract geometric and material details from the CAD model. In the work described here, the tagging technique has been used. As seen in Figure 2, the parameters are created in the CAD environment and the model measurements are to be tagged to these parameters. A VBA (Visual Basic for applications) code can be introduced to automate this activity in the CATIA environment.

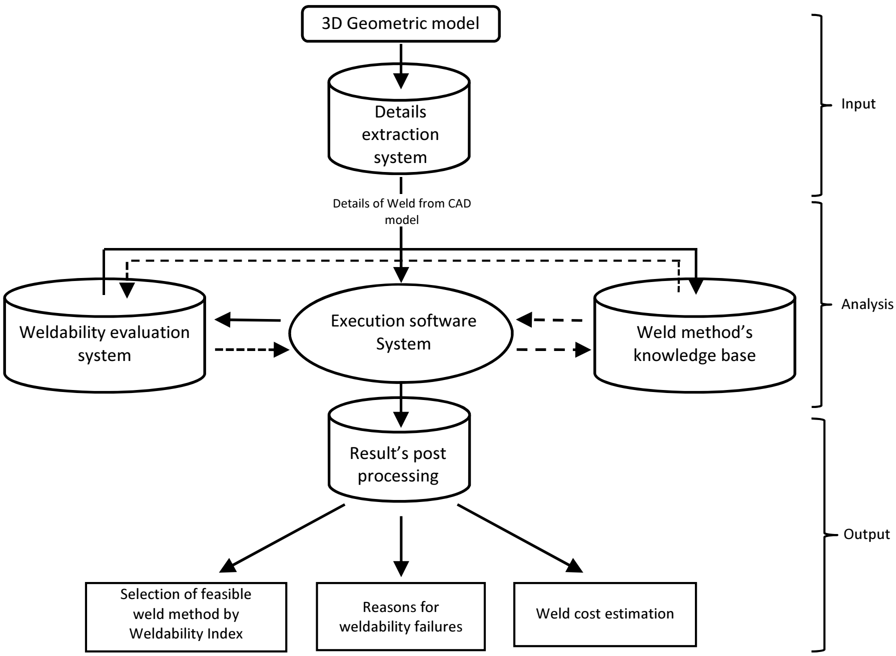

Figure 1. An approach to evaluate the weldability of a part from its CAD model.

2.4. Weldability evaluation system

In order to evaluate the weldability, a set of verified rules are required to analyse the weldability of a design. The rules are used to analyse the proposed design in different aspects, such as; material feasibility, shape, tool accessibility and etc. These rules have been extracted from various sources such as scientific literature, welding data handbooks, Weld equipment operation manuals, industrial standards or best practices, company own design procedure and other valid data. Usually the available rules are documented in the form of simple text. For example: Tanigawa *et al.* [24] have defined that the allowable initial gap of 0.2 mm and the allowable linear misalignments are 0.7mm for laser welding. In order to verify the weldability of a component with these definitions, an evaluation is needed. The developed weldability evaluation rules are similar to the Vishal Naranje's [18] production rules with 'IF-THEN' logic with Liu HongJun's [16] constraint-based technique. The rules have been developed in MS-Excel due to availability and maintainability considerations.

The extracted information from the CAD model is sent to the MS- Excel based rules. Subsequently, the rules will be evaluated by referring to the *Weld method's knowledge base*. The rules are managed by the system allowing version control.

Required rules will be connected to the *Execution system* based on evaluation requirements.

2.5. Weld method's knowledge base

A weld method's knowledge base is a data bank for all available weld methods and their capabilities. Examples of capabilities includes allowable weld materials, allowable thickness range, required filler material, type of welds, positions and so on. The details are documented for each available weld method separately. The capabilities of each weld method are subjected to the weld machine size and available weld technology. The descriptions of the weld methods, that is the weld data sheets are updated with time and new weld machines will replaces the old machines. For that, the developed weld method's knowledge base has been established such that it is upgradable according to the changes. Before use of this tool on manufacturing level, an appropriate knowledge base has to be prepared in the form of 'weld method data-sheets' for each available weld method with their capabilities.

2.6. Execution system

The role of an execution system is to execute a task *i.e.* doing weld analysis automatically. The execution system will integrate all weldability analysis' subsystems. The execution system has been prepared in the Howtomation© suite [7]. Once the execution system has been developed in the Howtomation© suite, the subsystems can be attached to this execution system easily. The execution system consists of three parts INPUT, ANALYSIS and OUTPUT. The *Details extraction* is connected to the INPUT part. The INPUT part observes the design information and sends it to the ANALYSIS system which consists of *Weldability evaluation system*. The ANALYSIS system will evaluate the weldability of a design with a set of predefined rules and gives the evaluation results in terms of the weld difficulty and the reasons for these difficulties. The results are conveyed to the OUTPUT part. The OUTPUT part consists of a *Result's post processing system*, which process the results taken from each evaluation rule for each weld method for each weld joint and gives a summary of the weld analysis including WI and approximated 'cost of welding'. Figure 5 shows a view from the execution system.

2.7. Result's post processing system

The purpose of result's post processing system is to make a summary of results from the analysis results in a defined format. After the *Weldability evaluation,* the details of information such as; weld difficulty, reasons for poor weldability, weld method, object or joint name, rule number and overall rule validity result will be transferred to the OUTPUT part. During the post processing the information will be summarized according the weld method and weld joint. The weldability index is calculated based on weld difficulties and the cost calculation is based on weld length, number of runs and filler material.

3. Illustrative Model

The developed weldability analysis system has been applied to evaluate weldability of a jet engine component. An illustrative example of a fictitious engine component with details extraction is provided. This CATIA Part file has been attached to the input part of the execution system (Figure 5). The input part of the execution system is in turn connected to the analysis part, which consist of weldability evaluation system in the form of rule checks.

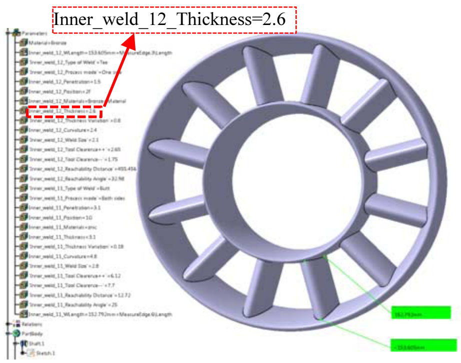

Figure 2: Illustrative model for weldability evaluation.

Different weld checks can be seen in the analysis part. Each of the MS-Excel evaluation files are connected to these objects in Howtomation, allowing them to be executed in an order determined by the inference engine. The evaluation rule checks are based on 'IF-Then' logic by comparing the inputs received in the MS-Excel evaluation file with the selected weld method's weld method data-sheet. As an example - if the material is not suitable to weld or if the thickness is out of feasible range, then the result becomes "not OK" for the thickness feasibility check. The reason will be shown to the user in the results section. The reasons are: 'Material is unfeasible for weld' or 'The plate thickness is out of feasible range'. If the thickness is feasible then it will calculate the 'difficulty' based on the level mentioned in the knowledge base (weld method data-sheet). The process is visualised by showing colours in the icons. Figure 5 shows a screen shoot from Howtomation.

Object Name	Weld Method	Weld Feasibility	Cost	Weldability Index
Inner_weld_11	TIG	ok	305.75	0.432461538
Inner_weld_11	LaserBeam	not ok	1222.59	-3.07692E+12
Inner_weld_12	TIG	not ok	307.38	-3.84615E+12
Inner_weld_12	LaserBeam	not ok	1382.70	-5.38462E+12

Figure 3: Summary of results.

The evaluation results from each rule check icons in the analysis system are connected to the output part. After the analysis of the evaluation rules, the results, reasons and the difficulty levels, which are based on given

Object Name	Weld Method	Rule .No	Rule Detail	Feasibility	Remarks	Decision
		WMM001.A01159	The component "material" must be suitable to the weld method	Yes	Material is weldable	
		WMG001.A01159	The "Plate thickness" should be lower than the weld method capability	YES	The Plate thickness is feasible to weld. The plate thickness is 3.1. The maximum allowable thickness is 45 and the minimum thickness required is 2	
		WMS001.A01159	The Required "weld penetration" is lower than the weld method higher value	YES	Required weld penetration is Possible because the required penetration is 3.1 and the weld method can do maximum of 8 and the minimum of 3	
		WMS002.A01159	The "Thickness Variation" is allowable to the weld method	YES	Defined thickness variation is suitable because the part thickness variation is 0.18 and the weld method maximum possibility is 0.2	
		WMG003.A01159	The required "Weld Thickness" must be higher than the chosen weld method's minimum value	YES	The weld size is suitable to weld because the part weld size is 2.8 and the weld method maximum possible weld size is 7 and the minimum are 2	
		WAG003.A01159	The "Curvature" is possible to the weld method	YES	Defined curvature is suitable to weld because the required curvature is 4.8 and the weld method's maximum allowable curvature is 5	
Inner_weld_11	TIG	WAG007.A01159	The "Tool Clearence"must be enough for the weld gun movement	YES	The tool clearence is suffecient because the required clearence is 6 and the possible clearence is 7.7	ok
		WAG007.A01159	The "Tool Clearence"must be enough for the weld gun movement	YES	The tool clearence is suffecient because the required clearence is 6 and the possible clearence is 6.12	
		WAG004.A01159	The "Reachability angle" must be sufficient to reach the weld gun	YES	The reachability angle is suffecient because the required reachability angle for the weld method is 12 and the possible angle is 25	
		WAG005.A01159	The "Reachability Distance vertical" must be must be sufficient to reach the weld gun	YES	Reachability distance is Suffecient because the maximum possible Reachability distance is 15 and the available Reachability distanceis 12.72	
		WAG002.A01159	The "Process mode" most be compatible to the weld method	YES	The Process mode is possible to weld	
		WMG002.A01159	The "Weld type" is feasible to the weld method	YES	The weld type is suitable	
		WAG001.A01159	The "Weld position" must be compatible to the weld method	YES	The weld position is suitable to the selected weld method	
		WMM001.A01159	The component "material" must be suitable to the weld method	Yes	Material is weldable	
		WMG001.A01159	The "Plate thickness" should be lower than the weld method capability	YES	The Plate thickness is feasible to weld. The plate thickness is 3.1. The maximum allowable thickness is 45 and the minimum thickness required is 2	
		WMS001.A01159	The Required "weld penetration" is lower than the weld method higher value	YES	Required weld penetration is Possible because the required penetration is 3.1 and the weld method can do maximum of 8 and the minimum of 3	
		WMS002.A01159	The "Thickness Variation" is allowable to the weld method	NO	Defined thickness variation is not suitable to the selected weld method because the part thickness variation is 0.18 and the weld method maximum possibility is 0.02	
		WMG003.A01159	The required "Weld Thickness" must be higher than the chosen weld method's minimum value	YES	The weld size is suitable to weld because the part weld size is 2.8 and the weld method maximum possible weld size is 7 and the minimum are 2	
		WAG003.A01159	The "Curvature" is possible to the weld method	NO	Defined curvature is not suitable to the selected weld method because the required curvature is 4.8 and the weld method's maximum allowable curvature is 1	
Inner_weld_11	LaserBeam	WAG007.A01159	The "Tool Clearence"must be enough for the weld gun movement	NO	The tool clearence is not suffecient to the selected weld method because the required clearence is 22 and the possible clearence is 7.7	not ok
		WAG007.A01159	The "Tool Clearence"must be enough for the weld gun movement	NO	The tool clearence is not suffecient to the selected weld method because the required clearence is 22 and the possible clearence is 6.12	
		WAG004.A01159	The "Reachability angle" must be sufficient to reach the weld gun	YES	The reachability angle is suffecient because the required reachability angle for the weld method is 22 and the possible angle is 25	
		WAG005.A01159	The "Reachability Distance vertical" must be must be sufficient to reach the weld gun	YES	Reachability distance is Suffecient because the maximum possible Reachability distance is 15 and the available Reachability distanceis 12.72	
		WAG002.A01159	The "Process mode" most be compatible to the weld method	YES	The Process mode is possible to weld	

Figure 4. Results from each rule check icons for each weld method.

inputs will transfer to the output part. The output part is attached with the result's post processing system which makes a summary of results with weldability index, weld cost and the weld feasibility from the analysis results in a defined format (Figure 3). In case of manufacturing conflicts between the design and welding a negative WI value indicates as infeasibility. Then the designer can verify the infeasibility parameters with the reasons (Figure 4). This work gives a solution to the manufacturing industries to consider manufacturing infeasibilities in design stages.

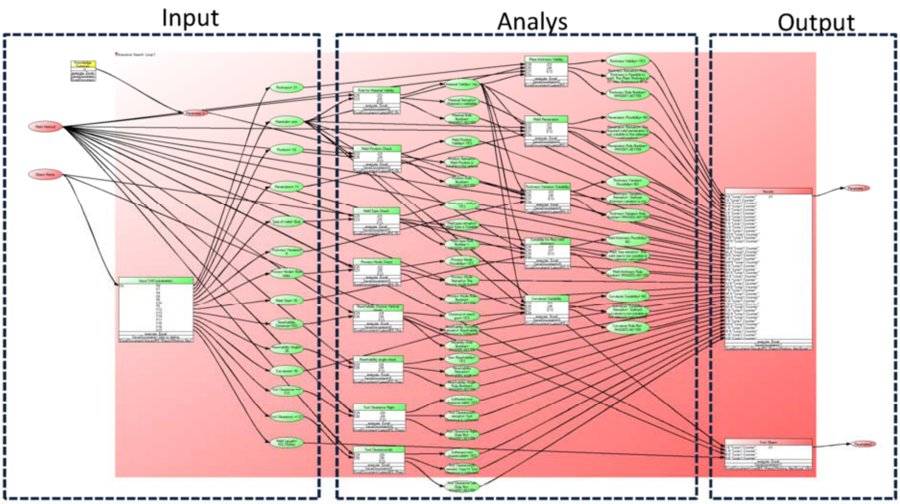

Figure 5. Execution system for weld analysis.

4. Discussion

This work demonstrates successful implementation of knowledge base engineering concepts for developing weldability analysis system. Process transparency and detail traceability have been achieved. The advantage of using Howtomation© suite is that a user can see the work in progress on the screen and is able trace the details of the weld evaluation. All the subsystems are integrated and automated with the execution system developed in the Howtomation suite. These discrete subsystems are prepared in such a way that they are easily maintainable and upgradable as technological improvements are being made. The weld evaluation rules have been made so that the rules can be updated with different versions and it is possible to extend the rules for manufacturability evaluation of other processes than welding. The weld method's knowledge base is kept separate so that weld methods can be added and removed easily. The existing weld methods are also readily updated by revising the process data sheets.

There are some foreseen limitations in the implementation of the system in the industrial environment. The system is unable to detect the uncompleted input information which will result in manufacturing unfeasibility. As emphasized by other researchers, there is a difficulty to do automation for welding gun interference for 3D natured welding paths. Further, the details of the extractions of tagged features are also not fully automated. It needs some manual intervention to identify the type of weld joint (Ex: tee, lap, etc.), weld direction with gravity direction and so on. It increases the preparation time of the CAD model and multiplies with the number of weld joints in the model. However, for a single manufacturing concept, the input model preparation can be automated with VBA code. The rule preparation, making different rule versions and the rule addition and deletion needs some programming skills from the staff who will operate the system. The constraint-base evaluation is limited to six degrees of freedom variables. For higher degree variables, another constraint solver has to be used. As a part of the future works, these difficulties will be solved along with the introduction of PDM system for rule management and weld sequence optimization.

5. Conclusions

The weldability analysis system has been developed according to the requirements of the aerospace company. It is an advantage for ETO industries to evaluate weld feasibility and approximate weld cost in early design stages. The developed weldability analysis system is an integrated part of an automated multi-objective design analysis system which is an integration of all functional analysis such as; Elasticity analysis, buckling analysis, fracture analysis, thermal analysis, manufacturability analysis and so on. The developed automated weldability analysis system is not only capable of analysing weldability of a design, it is also able to report potential issues back to the designer and selecting the most appropriate weld method. The Weldability index and approximated weld cost can help the selection of the most favourable weld method.

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A Model for Advanced Manufacturing Engineering in R&D Technology Projects Through DFMA and MRL Integration

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Abstract. The aim of this paper is to present a model that takes into account aspects related to manufacturing engineering in research and development projects. The proposed model integrates the tools of DFMA (Design for Manufacturing and Assembly) and MRL (Manufacturing Readiness Level).Design for Manufacturing and Assembly is used as a method to provide guidance to the design team in simplifying the product structure, to reduce manufacturing and assembly costs, and to quantify improvements. Manufacturing Readiness Level (MRL) is a measure to assess the maturity of manufacturing readiness, similar to how Technology Readiness Levels (TRL) are used for technology readiness. The proposed method was applied in a research and development project at a refrigeration industry, in its technology definition phase. The results were a significant change in product design, bringing benefits as reduction of investment and product cost by 25% and 20%. Is also possible perceive that the anticipation of the manufacturing project, when working simultaneously with the technology maturation is allowing the most reliable debugging at a product, permitting a reduction in the lead time.

Keywords. Design for Manufacturing and Assembly (DFMA), Manufacturing Readiness Level , Advance Manufacturing Engineering.

Introduction

Increasingly, more industry sectors have been affected by the growing and rapid increment of competitiveness, driven by strong level of globalization. Industries are forced to change its way to design and manufacture to deliver the necessary results considering different market situations, whether by government policies or even of each individual company policies. Considering this approach, companies are looking for to integrate Manufacturing Engineering and Research and Development, for example the refrigeration company quoted here, called as industry R. The Manufacturing Engineering working in advanced stage of product development process can help make project in a more efficient way. Efficiency is doing things right and effectiveness is to do right things [1]. The first is related to the operation, which is the optimization of resources means, methods and processes that is how to make the things.

The proposal to increase this efficiency is implement a framework to evaluate the Manufacturing Readiness Levels (MRLs) and Design for Manufacturing and Assembly Methodology (DFMA) through a matrix and apply this matrix on Technology and

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Innovation (T&I) phase. This framework is applied in industry R product development process cycle. MRL is responsible for, defining the current level of manufacturing maturity, identifying maturity shortfalls and associated costs and risks in addition to providing the basis for manufacturing maturation and risk management implementation [16]. The DFMA is used as the basis for concurrent engineering studies to provide guidance to the design team in simplifying the product structure to reduce manufacturing and assembly costs, and to quantify the improvements [2].

1. Conceptualization

To introduce MRL is necessary understand current product development process framework for industry R. As shown in Figure 1, the process is structured in phases and decision gates to approval phases. This method is characterized as a system development broken down into a number of sequential sections or stages represented by boxes. The outputs from one stage are used as inputs to the next This framework is the product development process reference model (PDP) that consists of a set of activities through which one seeks, based on market needs along with technological possibilities and constraints, as well as considering the company's competitive and product strategies, to reach a product's design specifications and its production process, so that manufacturing is able to produce it. [4]. In this proposal the MRL should be a tool to support project management decision to in each PDP gate considering the Manufacturing Engineering assessment that is based on index of manufacturability and reliability

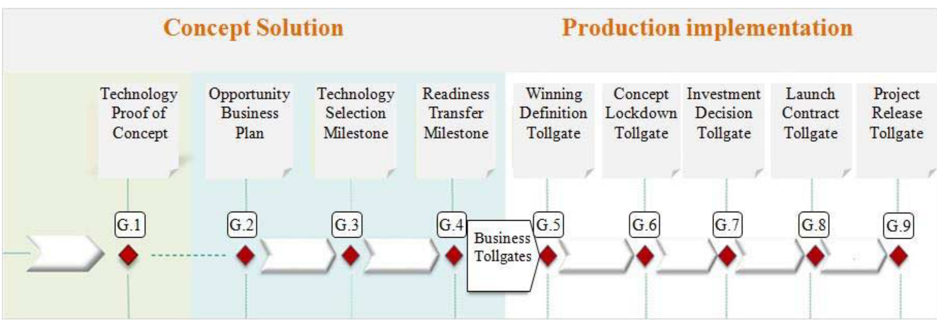

Figure 1. Product Process Development framework for industry R.

2. Design for Manufacturing and Assembly (DFMA)

The term design for manufacture (DFM) means the design for the ease of manufacture of the collection of parts that form the product after assembly and design for assembly (DFA) means the design of the product for the ease of assembly. Design for manufacture and assembly (DFMA) is a combination of DFA and DFM [2]. There are several DFMA methods or techniques for concurrent engineering development, but the three most well-known are probably the Boothroyd Dewurst DFMA method, the Hitachi Assemblability Evaluation Method and the Lucas DFA Technique [5].

Booth, Lucas and Boothroyd methods have common features and connected topics. Lucas DFA procedure was developed by University of Hull in conjunction with Lucas Engineering. The base of methods is from the same research project as the Boothroyd & Dewhurst DFMA. Thus, these common feature are reduce part numbers and analysis of part geometry for assembly process.

Figure 2 summarizes the steps taken when using DFMA during design, making a parallel about Boothroyd and Lucas methodology. The DFA analysis is first conducted leading to a simplification of the product structure. When DFA began to be taken seriously in the early 1980s and the consequent benefits were appreciated, it became apparent that the greatest improvements arose from simplifying the product by reducing the number of separate parts [2].

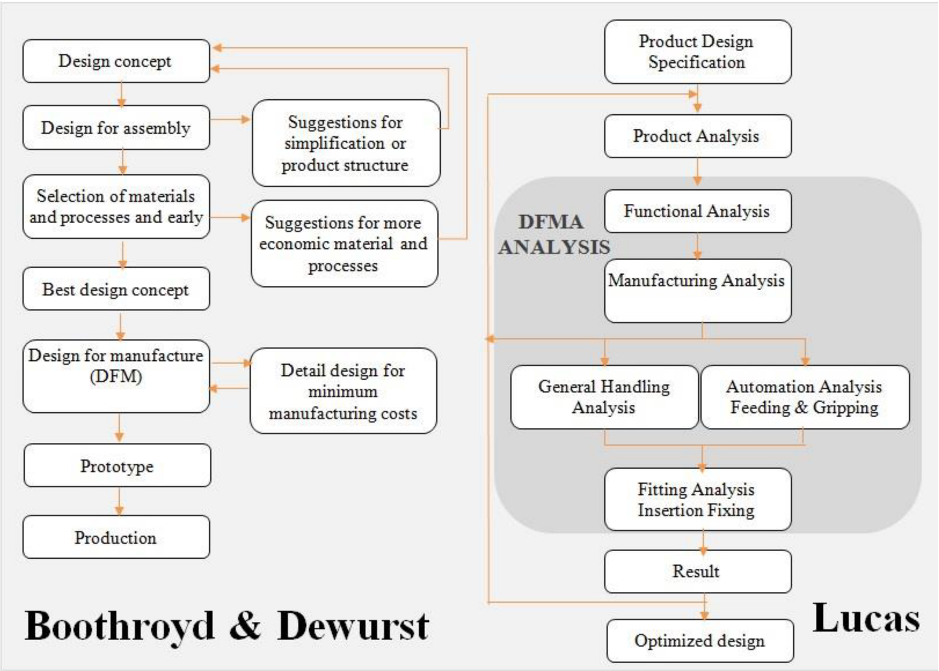

Figure 2. Boothroyd and Lucas DFMA application steps [1] [3].

Either Lucas or Boothroyd methods has the first relevant step called functional analysis, both use analogous criteria [2], the objective is the same, reduce part count. The use of Functional Analysis together with DFA able the design team in identifying those parts that are candidates for removal or combination. This involves asking a series of questions to identify which parts of the product are essential or not as well witch parts can be optimized. As a results, the design / manufacturing team has the parts of the product classified in part Type A and Type B. By definition, a type A part is functionally necessary and a type B part should be eliminated or combined where possible [3]. Figure 3 presents a Lucas flowchart, although Boothroyd proposes a similar analysis through 3 questions answers.

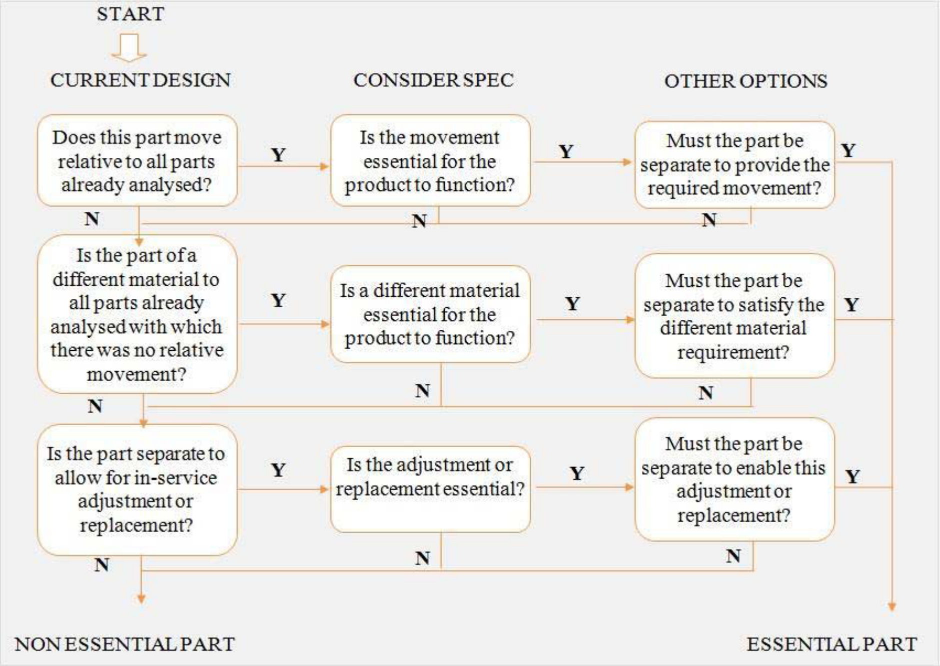

Figure 3. Lucas flowchart funtional analysis [3].

Following the functional analysis there are two ways to evaluate assembly efficiency, Boothroyd presented in Equation 1 where N_{min} is the theoretical minimum number of parts, T_a is the basic assembly time for one part, and T_{ma} is the estimated time to complete the assembly of the product [1] or Lucas presented in Equation 2 where A is the theoretical minimum number of parts and A+B is the total number of parts [3].

$$AEf = N\min(Ta/Tma) \quad (1)$$

$$AEf = A/(A+B) \quad (2)$$

Both methods have a threshold for design efficiency, Boothroyd follows a tendency based on manual assembly and Lucas suggest design efficiency threshold 60% but a practical working target if often taken as 45% [2].

As a result of experience in applying DFA, it has been possible to develop general design guidelines that attempt to consolidate manufacturing knowledge and present them to the designer in the form of simple rules to be followed when creating a design.

3. Manufacturing Readiness Level (MRL)

The definition of MRL is related the conception of technology readiness level (TRL).

Nazanin et al (2009) explain that “Technology Readiness Level (TRL) is a metric that was initially pioneered by the National Aeronautics and Space Administration (NASA) Goddard Space Flight center in the 1980s as a method to assess the readiness and risk of space technology Over time, NASA continued to commonly use TRLs as part of an overall risk assessment process and as means for comparison of maturity between various technologies

In parallel of maturity technology scales measures development was developed the a similar scale to measure the manufacture. The idea was to apply a similar scale addressed in TRL but applied in manufacturing field of knowledge [11].

Manufacturing Readiness Level (MRL) definitions were developed by a joint DoD/industry working group under the sponsorship of the Joint Defense Manufacturing Technology Panel (JDMTP). The intent was to create a measurement scale that would serve the same purpose for manufacturing readiness as Technology Readiness Levels serve for technology readiness – to provide a common metric and vocabulary for assessing and discussing manufacturing maturity, risk and readiness. MRLs were designed with a numbering system to be roughly congruent with comparable levels of TRLs for synergy and ease of understanding and use, (Manufacturing Development Guide, 2010). There are ten MRLs (numbered 1 through 10) that are correlated to the nine TRLs in use. The final level (MRL 10) measures aspects of lean practices and continuous improvement for systems in production.

After the DoD implemented the MRL in 10 steps, there were derivations, the first concerns about the Rolls-Royce, responsible for development of turbines for aircraft, which created a scale of 9 steps based on the scale proposed by DoD, call Manufacturing Capability Maturity Level (MCRL) where each of the nine steps of TRL is connected directly with MCRL, and is applied to the entire "supply chain"[11] (Figure 4). In addition to the Rolls-Royce range, two other scales aimed to determine the level of maturity of manufacturing processes were created, the first was (IMRL) created by the nanotechnology industry due to the high differential appeal of innovation, which is also based on the TRL model, and the second used by the Department of Aviation General Electric in 2010 which confirms that the use of TRLs and MRLs are the right way to act systematically to reduce risks and create a common language throughout the industrial base. MRL specifically gives its return to the company by adding value to process capability and maturity of the production plan.

Each one of these 10 MRLs has a specific objective that goes from basic manufacturing issues up to full rate production and best practices, following Manufacturing Readiness Level (MRL) Desk book (2011) definitions.

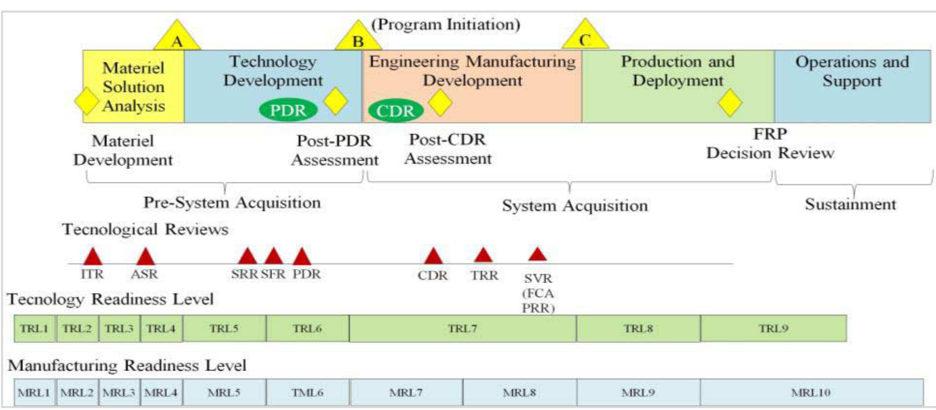

Figure 4. DoD Acquisition life cycle.

4. Proposed model

The process supported to measure in the project the manufacturing maturity level associated with DFMA rules is presented on Figure 5. The scheme of the process includes inputs, tools & techniques and outputs. The input is the product design proposal and the output is the maturity evolution indexes. And, to support this process was developed a DFA and DFM evalution sheet and DFMA&MRL matrix.

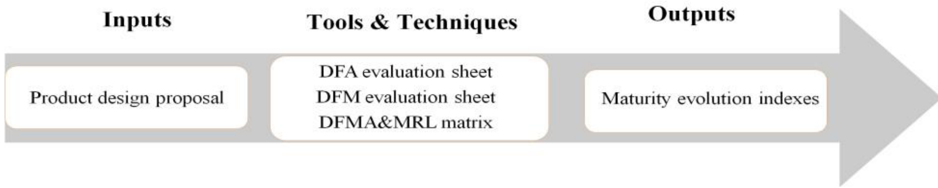

Figure 5. Manufacturing maturity evaluation process.

DFA evaluation sheet is an adaptation of DFA evaluation spreadsheet from Stienstra (2016) and Sohan (2015) including Lucas Methodology sub-factors and penalty scores to be possible make the math used to calculate final scores. Lucas methodology was selected for this evaluation due to be possible proceed with analysis without numeric evaluations about cycle time, which is strictly necessary at the beginning phases of the project where there are only concepts of product. The spreadsheet is divided in 8 levels, identified as L1 to L8 in Figure 6, level 5 (L5) is the most important because it is the part that the project team will fill in, comparing product component design according factors presented on level 2. Item 5.1 must be filled in with Bill of Material from a design under evaluation, 5.2 must be filled in with the number of components related to the Bill of Material (BOM) and field 5.3 must be used Yes or No, Low, Medium or High according to the answer drivers on level 3 as for example in Figure 6. Level 1 (L1) has the main factors that the project's design will be analyzed, level 2 (L2) are sub-factors deployed from (L1) that permit a more accretive analysis about each item. Level 3 (L3) presents the answer drivers to be inserted on field 5.3 during project analysis, level 4 (L4) has the penalty factors that will be used to calculate total penalty scores for handling and fitting. As soon as the project team has finished to fill in level 5 the results will be presented on levels 6, 7 and 8, where level 6 (L6) is the total score created to be possible differentiate different component designs. This score correlates levels 4 and 5, and the calculation method is presented in Equations 3 and 4. Equation 3 is applied for DFA complexity, Functional Analysis & Redesign Opportunities and Full Proof, while Equation 4 is used for Handling and Fitting using penalty factors (PFmax and PFmin) from level 4 DFA evaluation sheet, Figure 6.

$$Total = \sum YES \tag{3}$$

$$Total = \sum NO \times PFMax + \sum YES \times PFMin \tag{4}$$

Level 7 (L7) aims to relativize rough numbers from equations 3 and 4 to be possible make a comparison among designs and projects. From (a) to (f) Equation 5 is applied and the best score is 100%. From (g) to (u) Equation 6 is applied, this value aims present penalty factors, so the best score is 0. To finalize spreadsheet level 8 (L8) there is the DFA global index, a metric used to be possible compare different designs and projects in a higher level along its life cycle, and are grouped by common objectives : DFA Index (AA), Cost Drive Index (BB), Full Proof Index (CC), Handling Index (DD), Fitting Index (EE), , and Other Operations Index (FF).

$$DFApartial\,index = \frac{\sum YES}{\sum YES + \sum NO} \times 100\% \tag{5}$$

$$DFApartial\,index = \frac{Totals}{b} \tag{6}$$

L1	Component of Subsystem identification	DFA complexity	Functional analysis & Redesign opportunities			Full proof		Handling							Fitting							
L2	Insert a Drawing View of component of Subsystem	Number of parts (Np)	Theoretical minimum part	Standard Part	Relative Cost	Wrong part	Wrong way	Tangle,Nest,Sticky	Flexible	Fragile	Sharp,Abrasive	Slippery	Rotation, Oientation	Plier , 2 hands	Align,Locate	Holding down	Insertion	Obstructed access	Self-holding	Screw,drill,bend, rivet,twist, crimp	Snaps	Weld or adhesive
L3	Answer driver	N.A	Y/N	Y/N	L/M/H	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
L4	Penalty factor Minimum (PFMin)	N.A	N.A	N.A	N.A	N.A	N.A	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0
	Penalty factor maximum (PFMax)	N.A	N.A	N.A	N.A	N.A	N.A	2,0	0,6	0,4	0,3	0,2	0,4	1,5	0,7	2,0	0,6	1,5	2,0	4,0	0,7	4,0
L5	**1 SB 1**																					
	1.1 Comp.A	x	Y	Y	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	1.2 Comp.B	y	Y	Y	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	1.n Comp.N	z	N	N	H	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	n SB n 5.1	5.2									5.3											
	n.1 Comp.A	w	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	n.2 Comp.B	k	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	n.n Comp.N	j	Y	Y	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
L6	Totals	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u
L7	DFA partial Index	A		B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
L8	DFA global index	AA		BB		CC		DD							EE							FF

Figure 6. DFA evaluation sheet.

To complete DFMA analysis a DFM evaluation sheet is used, Figure 7 that gives 3 DFM partial index, manufacturing relative costs (Rc), manufacturing processing cost (Pc) and manufacturing material costs (Mc), which will be grouped to form a DFM Global Index called Manufacturing Cost Index, following the logic of DFA Partial and Global Indexes. It must be used with the same BOM list used on the DFA evaluation sheet. This spreadsheet follows the method proposed by the Lucas Methodology [7].

Volume	Shape Complexity	Qty	**Rc**	Cc	Cmp	Cs (Ct or Cf)	**Pc**	**Mc**	V	Cmt	Wc	**Mi**
Subsystem total												
SB 1												
Comp.A												
Comp.N												
SB n												
Comp.A												
Comp.N												

Figure 7. DFM evaluation sheet .

To know in what step of maturity (MRL) is the project, was done one adaptation on the MRL steps of the "DoD acquisition life, Figure 3, for the current PPD Industry R reference model, Figure 1. For the first step, although the product is different, a direct correlation was identified between the two cycles, DoD Pre System Acquisition and Industry R PDP up to CLT gate, and these correlations and MRL adaptation are presented in Figure 8.

To integrate MRL, DFA and DFM evaluation sheet was created a matrix called DFMA and MRL integrated matrix, Figure 10, where section A presents the the results of each maturity step under evaluation from MRL2 to MRL4 and a recommended threshold value to drive project decisions and risk assumptions. Section B is a space to insert a brief description about product changes from maturity steps evolution and C is a deployment of A to became easier for project management and project team identify the relevant points that must be planned for the next phase. To validate the model is done a Case Study applied at a real project at Industry R for MRL2 to MRL4 and measured the evolution.

DoD Acquisition Life Cycle	Pre systems acquisition					
	Materiel Solution Analysis				Technology Development	
DoD MRL	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6
Enterprise R PPD	TCP	OBP	TSM	RXM	WDT	CLT
Enterprise R MRL Adaptation	MRL1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6
	Basic Manufacturing Implications Identified [Shortfalls and Basic Research]	Manufacturing Concepts Identified[Applied research in solutions]	Manufacturing Proof of Concept Developed [Analytical laboratory experiments]	Capability to produce the technology in a laboratory environment [Technology Ready]	Capability to produce prototype components in a production relevant environment [Acess industrial base]	Capability to produce a prototype system or subsystem in a production relevant environment [Ready to start acquisiton program]

Figure 8. MRL adaptation for PPD at Industry R.

5. Model Application

The model was applied following the sequence presented in Figure 9, each box follows the rules previously oriented for Boothroyd and Lucas methodologies. The project team is responsible to fill in level 5 (L5) on the spreadsheet, Figure 6, on items 5.1 and 5.2 inserting data from the BOM list and number of components and item 5.3 filling in each blank space with an answer driver from level 2 related to each sub factor at level 2. For DFM evaluation sheet it's necessary to fill in the DFM sheet based on Lucas Methodology orientations.

Figure 9. Methodology sequence application.

6. Results

The model was applied in a project along of 3 phases of maturity, MRL2 to MRL4, by Process Manufacturing Engineering to support and drive product modifications. The results, as presented in Figure 10, were a modification in all concept design. With the increase in the DFA index, it was possible to reduce assembly risks with not known or complex technologies required to product previous design beyond of a reduction of transformation cost due head count reduction. Handling and Fitting were improved due product concept changes and will allow another step of improvement on the next phase. The investments on manufacturing process were reduced in 25% this results were driven by the manufacturing process cost index that presented an improvement of 49%, and the main impact was the change of precision machining operations for the stamping process. The design change also provided a product design cost reduction of around 20% due not be more necessary use of expensive materials or assuring tight tolerances for components. Another benefit was reducing project lead time due process engineering team work in advanced steps avoiding future looping during acquisition phase.

	DFA Index↑	Cost drive↑	Handling Index↑	Fitting Index↑	Full Proof Index↑	Manufacturing process cost index↑	Other Operations Index↑
Better	↑	↑	↓	↓	↑	↓	↓
Level Evaluation				MRL 4			
MRL 4 (A)	70%	45%	2,21	3,99	79%	92	1,14
MRL 3	61%	42%	2,21	4,14	76%	103	1,14
MRL 2	53%	35%	2,40	5,20	67%	212	1,50
Threshold Recommendation	>=60%	*Bt2	<=2,5	<=2,5	*Bt2	*Bt2	*Bt2
(B) **Product Change Point / Level of changes** All concept design was modified from MRL2 to MRL3 and a design optimization was done on MRL4							
Is it a **standard part**?		21%					
Component cost with **lower impact**		68%					
Meets the **Handling** rules: Not Tangle,Not Nest, Not Sticky			0,7				
Meets the **Handling** rule: Not flexible			0,1				
Meets the **Handling** rule: Not fragile			0,0				
Meets the **Handling** rule: Not sharp/Abrasive			0,0				
Meets the **Handling** rules: Not slippery (C)			0,0				
Meets the **Orientation** rule: It´s not hard to see rotational orientation			0,0				
Meets the **Size** rules: Not Necessary use Plier , Tweezers or 2 hands			1,4				
Meets the **Alignment** rule : Not difficulto to align,locate?				0,4			
Meets the **Process Direction** rule Holding down requirements?				0,3			
Meets the **Insertion Force** rule: Is it smoth to insert?(There´s no resistance)				0,1			
Meets the **Acess/Vision** rule:Has no obstructed access ?(good visibility)				0,3			
Meets the **Part Placing** rule: The part can be self-holding assembled?				1,7			
Meets the **Fastening A** rule: Can it be assembled without screw,drill,bend, rivet,twist or crir				1,1			
Meets **Fastening B** the rule: Can it be assembly without snaps ?				0,1			
Meets the rule: Is NOT possible assembly **wrong part**					100%		
Meets the rule: Is NOT possible assembly **wrong way**					53%		
Manufacturing **Relative Costs** (Rc)						44	
Manufacturing **Processing Costs** (Pc)						16	
Manufacturing **Material Costs** (Mc)						24	
Meets the rule:Is possible assemble **without** using weld or adhesive?							1,14

**Bt2 :(Better than previous maturity level), there is no scientific threshold for this index but must be better than previous maturity level.*

Figure 10. DFMA and MRL Integrated Matrix.

7. Conclusion

This model is a important tool to permit manufacturing process engineering work in a concurrent engineering environment mainly during the preliminary steps of research, due to the high influence on product design that will result in lower transformation and material costs, lower investments as well as shorter lead times, at the same time making it possible to follow the project maturity evolution considering aspects related to Process Manufacturing Engineering therefore avoiding and mitigating future risks that normally appear in the acquisition phase.

The limitation of this study is for preliminary steps of a project during concept definition and preliminary prototypes, future works can use other MRL levels and establish DFMA connections.

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Human-Driven Design-to-Cost Methodology for Industrial Cost Optimization

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Abstract. Over the years cost optimization has gained a strategic importance to realize competitive products. However, traditional approaches are no longer efficient in modern highly competitive industrial scenarios, where numerous factors have to be contemporarily considered and optimized. In order to be effective, design has to care about cost along all its phases. This paper presents a methodology that integrates Design-To-Cost (DTC), Design for Manufacturing and Assembly (DFMA), Human Factors (HF) and Feature-Based Costing (FBC) to include costs from the early conceptual design stages and properly drive the product design. Thanks to a structured knowledge base and a FBC approach, it predicts both manufacturing and assembly processes from the 3D geometrical models and estimate the global costs, more accurately than existing tools. The research demonstrates the method validity by an industrial case study focusing on cost optimization of packaging machines. Thanks to the proposed method, the main design inefficiencies are easily identified from the early design stages and optimization actions are taken in advanced, in respect to traditional design process. Such actions allowed reducing total industrial costs of 20%, improving machine assemblability and human ergonomics due to structure simplification, part number reduction, and production processes modification, and reducing the time spent for cost estimation (until -60%).

Keywords. Cost modeling, Cost optimization, Design-to-Cost (DTC), Feature-Based Costing (FBC), Knowledge-Based engineering (KBE).

Introduction

Nowadays, product and system design must contemporarily deal with and optimize numerous factors such as performance, aesthetics, time-to-market, sustainability, quality and cost [1]. Traditionally, a product cost target is defined at the beginning of the design process and verified at the end: whereas it is not respected, design is iteratively changed in order to find a compromise between performance and cost objectives by minor incremental improvements and long optimization loops. In this context, cost seems a performance indicator rather than a real design driver. Several studies demonstrated that a large percentage (at least 70% up to 80%) of product cost is already determined during the conceptual design phase and, once the product concept is defined, there is no much room for significant changes since total cost are almost already defined by product architecture, assembly procedure, quantity of components

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and their related manufacturing process. As a consequence, the majority of the costs are already frozen with product conceptualization and costs for the following product modification grow exponentially along the development process stages [2, 3].

Today several methods and tools are available to assist product managers in decision-making to evaluate the cost of alternative design solutions [4]: for instance, Design for Manufacturing and Assembly (DFMA) allows assessing the product cost by analyzing the production processes when the product is designed in details, while Group Technology (GT) and Computer-Aided Process Planning (CAPP) can manage the knowledge connected to cost definition. However, such tools have three main drawbacks:

1. they are usually “static” tools suitable for validation and verification;
2. they require a lot of information to provide a clear cost structure, so that they can hardly used from the preliminary design stages; and
3. they do not consider the human-related aspects so that human-based activities are difficult to model and predict.

As a consequence, their use is complex and time-consuming, and usually limited to advanced validation phases [4]. Furthermore, human-related activities are usually neglected from the process cost estimation because they can be hardly standardized and have been considered not important for final cost definition. Contrarily, it has been recently demonstrated that human-related actions highly affect the global efficiency and costs of industrial processes in different contexts of application, from material handling to assembly, from order picking to operations in line [5, 6]. At the present moment, the most common tool adopted by companies all over the world for early cost estimation and optimization is represented by excel worksheets supporting the experience of very skilled people able to make the right assumptions. However, such an approach is highly timewasting and subjective, and not fully reliable due to the necessary approximation and the possibility of human errors.

According to these evidences, the present paper proposes a Design-To-Cost (DTC) approach to estimate the product cost from the earliest design stages, which combines Design for Manufacturing (DFM) to model industrial processes and create a structured process knowledge base, Design for Assembly (DFA) to model the human-related actions and create a structured human knowledge base, and Human Factors (HF) to assess the human efforts and identify its efforts and related costs. Furthermore, it adopts Feature-Based Costing (FBC) principles to fasten the analysis by recovering the 3D geometrical features and link them to the related processes, both machining and human-driven, to predict the final costs. The main paper contribution consists of the adoption of human activity assessment for the definition of more accurate cost models.

1. Related works

The DTC approach aims to support cost-efficient product design by defining a clear target cost at the beginning of the design activity, to be respected along the process by properly managing the knowledge related to the production process [7]. According to DTC approach, cost analyses are fallen back to the early design stage so that the conceptual models continually interact with cost considerations. DTC is easy in its concept, but hard to implement in practice due to the complexity of the products and systems designed, and the complexity and variety of the production processes to be estimated and refined along the design process. Furthermore, the close relationships between performances, geometries, manufacturing process, aesthetics, and costs and the reciprocal effects of such factors make cost estimation a critical job in the conceptual stages. Moreover, costs are highly variable according to market demands, production volume, cost amortization, and other logistics costs. In order to be successful, DTC needs to be based on solid cost estimation models able to estimate the production costs according to consistent assumptions, when specific data are not available.

Among them, the Design for Assembly and Manufacturing (DFMA) theory was defined to assess efforts and costs related to fabrication and assembly processes [8]. In particular, DFA aims at reducing the number of components providing a list of criteria through which the effective need of each part can be evaluated, and DFM allows the manufacturing process optimization and provides elements of cost for each component (e.g. raw materials, set-up costs, processing costs, additional costs) [9]. Such estimation could be by manual procedures or dedicated software toolkits. A good review of the existing cost estimation methods has been recently provided by [10]: they can be distinguished in quantitative and qualitative. Qualitative estimating techniques, also called intuitive, rely on experience and knowledge of product cost estimators, being cheap and fast in implementation. Differently, quantitative estimating techniques use mathematical algorithms and statistical tools, and set the value of product cost with respect to the manufacturing process specifications [11]. More recently, the FBC approach proposed to identify the product features as geometric information and collect all functional and technological information (e.g. tolerances, surface finishing, manufacturing cycle, etc.) and to use knowledge-based systems to apply the most proper cost models [12, 13]. FBC seemed very promising approach since it allows anticipating the analysis from the early design stages, fastening the estimation process, and supporting the costing process by a software tool. However, the cost models proposed in literature are mainly focused on manufacturing processes, where machines operate and humans are considered as an additional costs of the machines, without considering whether and how Human Factors (HF) affect such cost models.

In this context, human activities have been recently analyzed and modeled mainly for ergonomic purposes, more than for cost models' definition. For instance, Maudgalya et al. [14] and Hendrick [15] investigated the effects of bad workplace ergonomics on productivity, quality of production, safety and costs, while Falck and Rosenqvist [16] assessed the cost of bad ergonomic performances for specific manual operations. Another interesting study defined an ontology that integrates human's knowledge and experience with product features and computational capabilities [17], but it focused on design parameters analysis rather than a real cost estimation. However, such studies demonstrated the importance of HF on the global process costs and suggested that also human-related aspects should be included into cost models to have a reliable cost estimation and effectively adopt a DTC approach.

2. The research approach

2.1. The Human-driven Design-To-Cost approach

The DTC research approach is based on the quantitative estimation of product-related costs and, in particular, exploits a FBC analytic methodology. The approach can be summarized into four main steps, as shown in Figure 1. The main phases are as follows.

1. *Process knowledge formalization*: the first step focuses on the formalization of both engineering process knowledge and human-related process knowledge, in order to define cost models with different levels of detail. In both cases, the knowledge base is structured by identifying a set of different process classes and dividing each class into categories. For instance, the production technologies are divided into classes (e.g. chip-forming machining, injection molding, stamping, die-casting, painting, thermal treatments, superficial covering, etc.), and each class into categories (e.g. machining class has been subdivided in milling, turning, grinding, gear cutting, broaching, slotting, etc.). Each category is further characterized by a set of typical operations, which define the specific cost model by mathematical formulas. Similarly, human-related processes are divided into classes (e.g. manual assembly, assembly with devices, handling, moving parts, etc.) and each class into categories (e.g. manual assembly class has been subdivided according to the part typology like pipes, rings, etc.). Therefore the operations are univocally mapped with a specific set of geometric and non-geometric elements defined as a set of features, to obtain a set of cost models. Each model combines the geometrical product parameters characterizing the specific operation (e.g. length, width, depth, roughness, etc.) with process characteristics (e.g. type of machine, machine power, number of operators required, human actions required, etc.). As far as engineering processes, the knowledge has been structured as suggested by [9, 13]. The same approach has been extended to cover also human-related processes, which are usually missing. In this way, the product design model (bi-dimensional or tri-dimensional) can be represented as a collection of process features. The knowledge formalization defines three main cost models: simplified, feature-based (FB) and detailed. The difference mainly lies in the number of parameters considered and the complexity of the mathematical models described. Usually this activity is carried out by people belonging to cost engineering department and with the involvement of the more strategic suppliers.

2. *Design concept optimization*: the second step consists of a preliminary optimization of the product design concept, expressed by a bi-dimensional or a tri-dimensional model, by the application of DFM and DFA techniques, but exploiting the wider knowledge base. At this stage, simplified cost models about both processes and human tasks are used to analyze the product structure and the main assembly sequences, inferred from the product structure by standardize models, as well as materials adopted and main technological processes. Such a step allows product simplification and optimization according to the process characteristics and estimated cost. At the end, an optimized 3D conceptual product model is defined. Usually this activity is carried out by designers.

3. *Feature-based cost estimation*: the third step starts from the decomposition of the 3D conceptual product model in its elementary geometrical features, and the correlation between its features and the manufacturing and assembly process stages, according to the FB cost models. Such models express the association between geometric product features and technological process features, that can be achieved only by a proper feature recognition algorithms and process knowledge formalization, in Step 1. During this step, the design features can be optimized according to a cost-oriented design; human tasks can be validated in time, security and costs; and different production scenarios can be simulated. Such analysis can be easily integrated within CAD tools and embedded into early design processes, in order to simplify and fasten the estimation process. This activity is basically carried out by designers, with the support of suppliers and partners in co-designing.

4. *Cost-oriented detailed design*: during the last step, product and process design is developed in details with adoption of detailed cost models, that take into account both process operations and human activities. At this stage, cost estimation of both product and process is very detailed, thanks to accurate models (considering also set-up costs, tooling, logistics, etc.) and is usually carried out in a parallel way. This activity is usually carried out by cost engineering and production technologists. According to the proposed methodology, this step can benefits from previous cost-oriented design actions and design is optimized easily and in a more effective way, in respect with traditional methods. A reduced number of design changes are required at this stage.

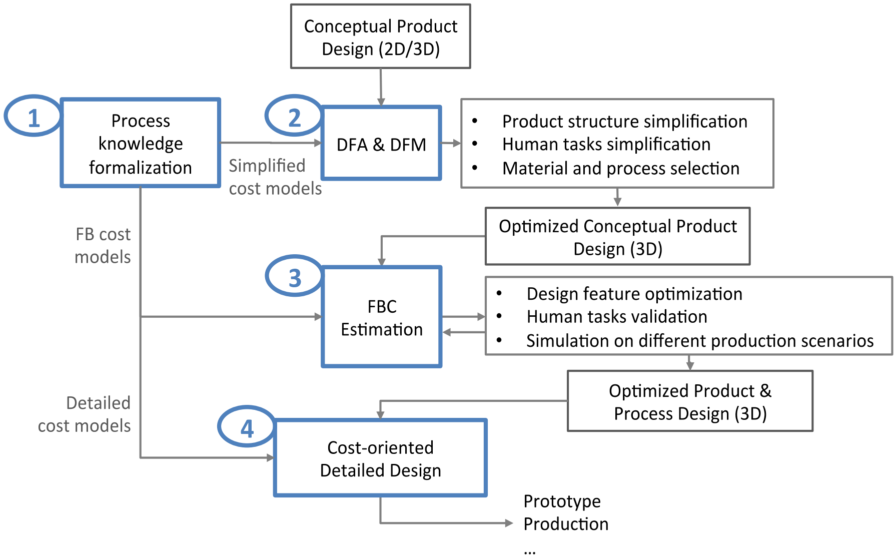

Figure 1. Human-driven DTC approach for industrial cost optimization.

2.2. The process cost modeling

This section describes in more details cost modeling and knowledge formalization, as mentioned in section 2.1. In particular, for almost any manufacturing process, costs are assessed by considering different types of times and hourly machine and plant cost. Three types of times are defined:

- *Active Time* (T_{ON}): time period when the machine / plant is running;
- *Accessory Time* (T_A): time spent for preparing to work a specific part even if the machine doesn't effectively work the part (e.g. time for machine changing tool or piece);
- *Set-up Time* (T_S): time spent for setting up the machine before starting working a lot production (e.g. CNC program testing, tool setting up);
- *Idle Time* (T_{OFF}): time period when the plant is idle;

For each of this time period, an hourly cost for each machine or plant is defined; the cost model is represented by a set of equations that combines the geometrical and technological parameters involved in the specific process. In particular, for each component manufacturing cost is composed by four cost items:

- *Operation cost* (C_O): cost for machining a part, calculated multiplying the time while the machine works the part by the machine unitary cost;

- *Stock cost* (C_S): cost for stock material, obtained multiplying the weight of the stock required by its unitary cost;
- *Ancillary cost* (C_A): cost related to accessory time, calculated multiplying the corresponding time by the machine unitary cost;
- *Machine set-up cost* (C_{MS}): cost related to the set-up time, obtained multiplying the corresponding time by the machine unitary cost.

An example about face milling is proposed. Table 1 describes the characterizing geometrical and technological parameters and the formulas. The cost estimation of face milling operation (C_{OP}) is calculated by the following equation (1):

$$C_{OP} = \left[\left(\frac{L+E}{VAs} * NPs * NWs\right) + \left(\frac{L+E}{VAf} * NPf * NWf\right)\right] * C_M \quad (1)$$

where C_M is the machine hourly cost, calculated on the basis of company data. Using the same approach, every automated manufacturing, assembly, logistic and management operation is described by a specific cost model.

Table 1. Example of feature-based costing process estimation (e.g. face milling).

Type	Parameter	Description (unit of measurement)	Relations
Geometrical	*L*	*Length [mm]*	*from 3D model*
	Lsp	*Shouldering length [mm]*	*from 3D model*
	P	*Depth [mm]*	*from 3D model*
	W	*Width [mm]*	*from 3D model*
	Ra	*Roughness [µm]*	*from 3D model or specifications*
Technological	*E*	*Over travel [mm]*	*= CONST*
	VAs	*Feed speed in rough machining [mm/min]*	*= f (material, machine)*
	VAf	*Feed speed in fine machining [mm/min]*	*= f (material, machine)*
	K	*De-burring width (W) in percentage [%]*	*= f (material, machine)*
	NPs	*Number of rough machining passes in depth [no.]*	*= CONST*
	PPs	*Rough machining pass depth [mm]*	*= CONST*
	PPsp	*Shoulder pass depth [mm]*	*= CONST*
	Ke	*Number of fine machining passes in depth [no.]*	*= CONST*
	NPf	*Number of fine machining passes in depth [no.]*	*= CONST*
	WI	*Width limit [mm]*	*= CONST*
	NWs	*Number of rough machining passes in width [no.]*	*= CONST*
	NWf	*Number of fine machining passes in width [no.]*	*= CONST*
	Df	*Milling cutter diameter [mm]*	*= from DB*

2.3. The human-oriented cost modeling

This section describes in more details human-related cost modeling and knowledge formalization, as mentioned in section 2.1. In particular, the activities carried out by humans are analyzed and divided according to their typology, and the related cost is assessed by considering the manpower hourly cost for the execution and additional costs related to the level of risk connected with the activities, that can cause injuries to workers according to ergonomic guidelines. Related costs are calculated according to the feature-based modeling and the proper knowledge base, and consequently the related costs are calculated. In particular, according to the DFA principles, human activities are classified into *handling* and *insertion*. The main product features considered are:

- *Thickness* (*T*): thickness of the handled item or part;
- *Size* (*S*): maximum dimensions of the handled item or part;
- *Weight* (*W*): weight of the handled item or part;
- *Orientation* (α): angle of insertion of the item or part;
- *Operation* (*Op*): type of operation executed (i.e. bending, riveting, screwing, fastening, soldering, adding material, etc.);
- *Level of difficulty* (*L*): level of difficulty of the specific operation (i.e. low, medium, and high). It is defined according to ergonomic principles, in particular Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Analysis (RULA) [18], on the basis of historical company data.

Furthermore, the following parameters are considered:

- *Labor hourly cost* (C_{HR}): hourly cost for workers involved;
- *Handing time* (T_H): time necessary for executing handling operations;
- *Insertion time* (T_I): time necessary for executing insertion operations;

Labor cost is defined according to the company rates, while standard values for T_H and T_I are defined for each specific type of operation by a set of logics based on experimental data. Operations are classified according to a specific set of the above-mentioned features. In some cases, a range of value is considered (e.g. for thickness, size, weight, orientation) according to the specific industrial sector. Table 2 shows the parameters considered for manual assembly, divided into geometrical and functional. Figure 2 shows an example of logics to assess the handing time (T_H).

Table 2. Example of feature-based human costing estimation (e.g. manual assembly)

Type	Parameter	Description (unit of measurement)	Relations
Geometrical	*T*	*Thickness [mm]*	*from 3D model*
	S	*Size (dimensions)[mm]*	*from 3D model*
	W	*Weight [kg]*	*from 3D model*
	α	*Orientation [deg]*	*from 3D model or specifications*
Functional	*L*	*Level of difficulty [no.]*	*= [1:10]*
	Op	*Type of operation*	*= f (process, T, S, W, α) from DB*
	T	*Tool supporting the operation*	*= f (process, T, S, W, α) from DB*
	H	*Handling condition*	*= f (process, T, S, W, α) from DB* *E.g. one hand, aided-one hand, two hands.*
	I	*Insertion condition*	*= f (process, T, S, W, α) from DB* *E.g. secured (or not), separated (or not).*
	A	*Access condition*	*= f (process, T, S, W, α) from DB E.g. easy, medium difficult, highly difficult.*

Handling ID	Category	Type	Tool	Param_0	Param_0_values	Param_1	Param_1_value	Line_value
one_hand	manipulation	assembly	hand	alpha	0;90;180	beta	0;90;180	0
one_hand	manipulation	assembly	hand	alpha	0;90;180;360	beta	0;90;180;360	1
one_hand	manipulation	assembly	hand	alpha	180;360	beta	180;360	2
one_hand	manipulation	assembly	hand	alpha	360	beta	360	3
aided_one_hand	manipulation	assembly	grasping tool	alpha	<=180	beta	>=0;<=180	4
aided_one_hand	manipulation	assembly	grasping tool	alpha	<=180	beta	360	5
aided_one_hand	manipulation	assembly	grasping tool	alpha	360	beta	>=0;<=180	6
aided_one_hand	manipulation	assembly	grasping tool	alpha	360	beta	360	7
two_hands	manipulation	assembly	hand					8
two_hands_large	manipulation	assembly	hand					9

Figure 2. Example of logics for handling time estimation.

3. The industrial case study

3.1. The case study description and objectives

The industrial case study focuses on the adoption of the proposed methodology to improve the design of complex groups of automatic machines in the packaging sector, with the final aim to reduce global costs and production times, as well as to improve the human safety and ergonomics during their production. Indeed, on the basis of experimental testing, we found that shorter and easier tasks can be accomplished in less time, but also with a lower effort and easier actions, with a consequence minor risk of physical and cognitive workload. In particular, the case study focuses on filling machines, where a flat web of packaging material is properly modeled in order to create a closed package. The packaging material is introduced by pushing a male die into a female channel and creates a delamination inside the packaging material layer fibers. A crucial group in filling machines is the co-called “forming ring”, which is realized in different sizes and mounted at different stages, through which the packaging material is modeled until the final shape. The forming ring requires high-quality processes in manufacturing and assembly, especially for food sector where the whole system have to be aseptic and all components have to respect severe tolerances and roughness values. Figure 3 shows the product 2D drawing and the 3D model. Such product has been re-design in order to reduce cost and improve the productivity.

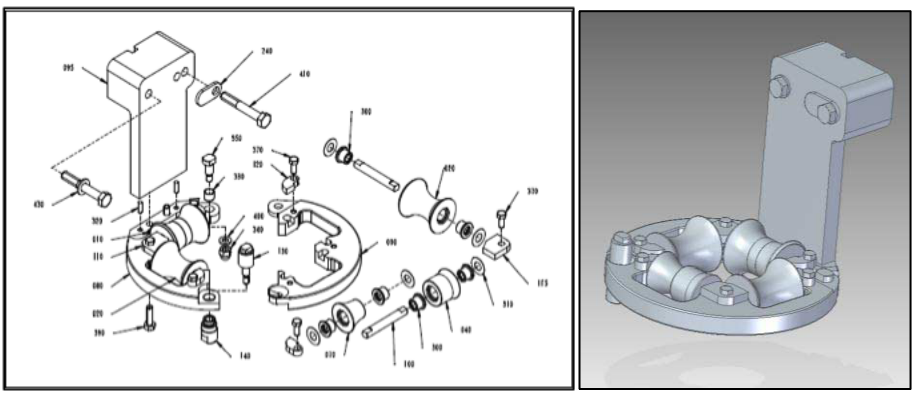

Figure 3. The case study product (i.e. forming ring).

In on-going production such product showed some criticalities, which the study aims to solve, in particular:

- High cost in respect to the total machine;
- Long time for cost estimation and optimization, for specific custom applications;
- Long assembly time;
- High number of components to be assembled;
- Low percentage of component reuse;
- Handling and insertion difficulties.

3.2. Results and discussion

During the case study the forming ring has been analyzed and re-designed according to the proposed methodology. First of all, the company knowledge related to the specific product was analyzed and formalized into a set of databases as described in section 2.1. About the human-related aspects, the sequence of operation were inferred from the production cycle and assessed in terms of times and level of risk. Indeed, the most common human postures during operations were mapped into a database and associate with a standard time and a standard value of RULA and REBA scores, according to ergonomic principles. After that, the manufacturing and assembly processes were analyzed and optimized. Cost estimation and optimization was faster and easier in respect to previous method thanks to the adopted FBC approach and the automatic identification of some features directly for the 3D model.

Results are shown in Table 3, where the main savings calculated on the optimized design in respect with the original design. Savings are distinguished in four categories: design, human factors, technological, and business. The first important benefit is the great reduction of the cost estimation time (-60%) that is achieved thanks to the automatic feature recognition from the 3D model according to the FBC approach. In this way, numerous simulations can be carried out easier and faster. Furthermore, the DFMA approach allowed reducing the number of components and interfaces (respectively -20% and -24%), while the human-driven approach allowed improving the quality of manual operations with a great reduction of handling and insertion difficulties (respectively -38% and -32%) and ergonomic risk (expressed by RULA and REBA) thanks to the reduction of fasteners and the easier assembly sequence. Such results brought to both technological benefits in terms of manufacturing and assembly times (respectively -16% and -37%), with a consequent impact of global industrial cost saving (-20%) and profit (+8%). The new design solution cannot be shown due to non-disclosure agreements.

Table 3. Saving obtained with the optimized product

Category	Indicator (unit of measurement)	Savings* (% on average)
Design	Time for cost estimation (min.)	- 60%
	Number of components (No.)	- 20%
	Number of interfaces (No.)	-24%
	Component reuse (No.)	+15%
Human Factors	Handling difficulties (No.)	-38%
	Insertion difficulties (No.)	-32%
	RULA	-20%
	REBA	-35%
Technological	Manufacturing time (min.)	-16%
	Assembly time (min.)	-37%
Business	Industrial cost (euro)	-20%
	Profit (euro)	+8%

** in respect to original design*

4. Conclusions

The paper presents a methodology to support industrial cost optimization of complex systems by the identification of the most critical issues in product structure and manufacturing and assembly process operations, considering both machining and manual operations. The main contribution of the paper is the enhancement of traditional Feature-Based Costing by human-driven approach, based on the optimization of ergonomics and Human Factors. An industrial case study taken from the packaging sector demonstrated the validity of the proposed methodology and the great achievable benefits. Thanks to the proposed method, the main design inefficiencies can be easily identified from the early design stages and focused optimization actions can be taken in advance. Result showed how the improvements of handling and insertion operations can bring great benefits on process time and cost, improve machine assemblability due to structure simplification, part number reduction, and production processes modification, and reduce time spent for cost estimation.

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Project of Automation and Cost Reduction at Spark Plugs Pressing System

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Abstract. This study deals with the gain in quality and cost reduction in the pressing of the spark plug wires from the need to ensure a standard, eliminate quality defects such as poor contact of the cables generating low power failures and unexpected problems. The objective was to study the best practices in the automotive industry, showing potential gains from the analysis of split costs by reducing the time of labor and applying the results on the production line. To understand this work some key points were studied such as: the system World Class Manufacturing (WCM), quality tools like PDCA cycle and Kaizen. These were applied in the pressing process of the spark plug wires, highlighting their advantages and disadvantages. The results show the implementation of automation press the spark plug wires in a positive manner towards the operation performed by the operator. Automation has been accepted and is planning to run the company in 2014. Referring to the layout of the production area there was a reduction in the cycle time of the post. In addition to that, it was observed the shortening of the cycle operator, with consequent reduction of costs and improvement in operator ergonomic point was observed.

Keywords. MTM, Quality, Continous Improvement

Introduction

The interest in having greater caution regarding quality emerged after World War II - the time when countries participated in the war were in urgent need of goods and the Japaneses were the first to be concerned with the quality of their production as they tried so hard to get back to market [1].

After a period of adaptation to the quality management systems and internalization of the concept, modern companies have given increasing emphasis to the role of quality in its products and services. This is because of globalization increasingly influence the daily lives of companies as well as customers, causing them to become increasingly demanding [2].

Always seeking to reduce costs, quality and time, the Alpha Company (fictittious name) and several other companies in the manufacturing and assembly industry, have adopted the World Class Manufacturing (WCM) as the main purpose and an everyday life concept. The World Class Manufacturing is a production system to enhance production standards and eliminate losses. Its principles are applied to all aspects of a plant, the quality maintenance system in a continuous improvement perspective [3].

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The problem did not occur at a specific time, but throughout the work shift with any operator and spark plug wires, and could possibly be linked to operator fatigue in the post by the high physical exertion.

Based on these principles, spark plug wires were identified at Alpha Company that there was no standard for fixing them in the engine, varying with the strength that each employee performed the impact with the hammer.

Current spark cables at the engine production line has been studied in order to solve a rework point of bad compressing the spark plug wires, requiring therefore more efficient and safe system to ensure the final quality of the product. It has been found no logical correlation with the spark plug wire, since the operation is done hundred percent manually making it difficult (nearly impossible) for the operator to follow the same level of force application and the contact point between the hammer and spark plug wire.

In order to correct the differences and to achieve continuous improvement as well as in product quality improvement at the press the job of the Alpha Company, this operation required a more efficient and reliable system that could guarantee the quality of the final product.

In this work is possible to find only the problems encountered due to poor pressing of spark plug wires in the engine related to labor and not the problems related to other parts of supply chain components, considering just two starting points: the quality problem of dealings and the other reducing the station cycle time for implementation of new activities in the workplace.

This paper considers the lean manufacturing concepts to assist in carrying out the activity and implementation of the equipment to be used. The used equipments in manufacture devices processes were produced by people trained at the company. This means that all device costs as well as quality level are Alpha's responsibility.

1. Literature review

The literature related to the Competitiveness & Production Control and Quality Level & Continous Improvement are reviewed and discussed at this space.

1.1. Competitiveness & Control

The current situation of competition between companies in various industry sectors makes them seek increasingly competitive advantages such as cost reduction and employee training. These advantages are achieved by using strategies, lean manufacturing tools, being all of them focusing on the product, quality, cost and efficiency [4]. The competitiveness is regarded increasingly as the key to success or failure of an organization at the market environment. It is the struggle for a wider area of operation which requires companies to adopt certain standardization of attitudes [5]. Quality is more than one factor that determines the survival of the organization [6]. Quality today is an investment. To shape up each organization is a must to management standards focusing at customer satisfaction. It is a top condition for the company to keep itself alive in the market. Therefore it is important to know and measure the performance of services to the customer or the delivered product [7]. It is possible to go further and state that manage the quality not only inserts the companies in the market competitively, but also provides a greater option of choice in terms of strategy. When high quality standards are achieved, it creates a capability that is not only differentiated. It also raises a strategy to lead while maintaining low cost. Contrary to what many entrepreneurs and laypeople think it is stated [8] that quality and low cost can be attributes to the same product without the need to opt for one of these objectives and leave the other in the background. Based on a case study [9] conducted in a large assembly plant, to improve the quality indices of a company is possible when there are changes in the culture of the company and its employees. Everyone must accept the idea that each employee plays a key role in improving certain process. For the authors, trained and skilled individuals are key to leverage innovations and, in addition, the changes made focusing on innovation standardize the quality, making possible the implementation of a global production system. This makes the company more competitive and enter further into the competition for greater market share. Some of the aspects where you can see the influence of Total Quality Control in production are [5] more and more products free of defects, deliveries performed safely and quickly, and the company's focus setting on continuous improvement and in customer satisfaction.

Total quality is a concept that somehow affect the satisfaction and needs of consumers [10]. Encompasses several areas, among which we can mention: quality, cost, delivery, moral values and security. So when one wants to have total quality within an organization, one needs to first assess the prerequisites, and then be able to have a clear vision of the goal can be achieved or not. A proposed quality management model [11], must contain a step to form work teams with active participation of employees to meet the expectations placed by the customer.

It is emphasized that the overall quality is not a program but a process [12]. A program assumes a beginning and an end, while a process is continuous, not delimited by spaces of time.

1.2. Quality Level & Continous Improvement

Some companies, especially in the automotive sector adopt some tools such as automation, quality tools, lean manufacturing, World Class Manufacturing, Toyota Production System, and others to achieve higher quality, greater efficiency, lower costs and continuous improvement to their factories. Therefore it is relevant to focus the main fundamentals and tools that can be used for a better production result.

It is necessary to compare the concept of quality to humanity itself [13], in the sense that both arose simultaneously. Since the beginning of the first pieces, good or bad, and the word "quality" has become part of the vocabulary of the people. Quality is a subjective term, without a universally accepted definition. The quality occurs when [10] a product or service meets to perfection and reliable, safe and accessible, customer needs. Another important factor in this concept is delivery of the product to the customer.

Based on the reliability of the product/process the quality shall meet the needs of consumers, with the quality or perceived quality, when a preference for a particular product is evident [10]. This preference most often are attracted by the low cost or due to the fact the expectation of consumption have been supplied on a large scale.

With very similar vision it is inserted the need to monitor the sectors that are part of the industry, and making up the product and services related to marketing, engineering, production and maintenance [14]. It can be said that the appropriate quality is also the concept that Taguchi measured because he focus experiments projects in order to increase profit and product quality, but noted not only the comfort that quality provides, but also the costs it can bring to society as a whole.

Taguchi also concerned himself with the realization of the specifications, for without them there are risks both losses as dissatisfaction [15].

Working groups [16] are the most essential element in the process of continuous improvement. Training, team building and improvements in the workplace are important elements to build an environment in which employees can grow, gain training and contribute to increased quality in the company.

1.3. Tools

KAIZEN: The history of Kaizen [17] starts the Toyota Production System, and states that is considered a key element in the Japanese management system as a principle of lean manufacturing. The thought began on the factory floor of Toyota Motor Corporation, due to scarcity of resources and market competition. Work was carried out to eliminate waste, developing tools such as just in time, kanban and poka-yokes. The concept was restricted to Toyota, until they realize that the problem was global, and Toyota was a big step forward to the other in a matter of management issues, and everyone should follow the way improvements were made. Kaizen is a set of activities in the factory, with the intention of improving the environment and operations. It is always solid, always looking for improvements to quality and efficiency. Its usage is so implicit that workers often act following the philosophy without realizing it. Kaizen is the continuous improvement process applied to reduce costs during manufacturing in the life cycle of a product.

PDCA:

The PDCA method (Plan, Do, Check, Act) [13], also known as "Deming Cycle" is one of the management qualities that allows the control of processes in order to make companies realize that there are no starting point nor an end in an activity, but rather a cycle to occur a continuous improvement process. PDCA cycle [18] is the troubleshooting that EW Deming developed to prepare the "Wheel Deming" with a cycle consisting of four steps: Plan (P), Do (D) Check (C) and Act Correctively (A). Also the PDCA cycle [19] is a tool that aims to maintain and improve the process and each phase of its application are used various tools of literature, with many different purposes and different nomenclatures.

At stage PLAN the company's goal is set and the action plans are defined in order to meet the goals. Please observe the problem to be solved, analyze the phenomenon and discover the causes of the problem. At the stage DO people receive proper training and following the action plans are implemented and the collected data to provide information on obtaining the goal. The CHECK stage is carried out an evaluation of the data collected in the previous phase. The last step ACTION depends on the results obtained in the examination, that is, the more information (facts, data and knowledge) are available, the greater the chances of achieving the desired goals. If the goal has been achieved, it is necessary to establish some means of communication of the obtained results. If not, it starts a new PDCA cycle in order to find other ways to get the expected results.

As an example, please take a look at Figure 1 of PDCA cycle.

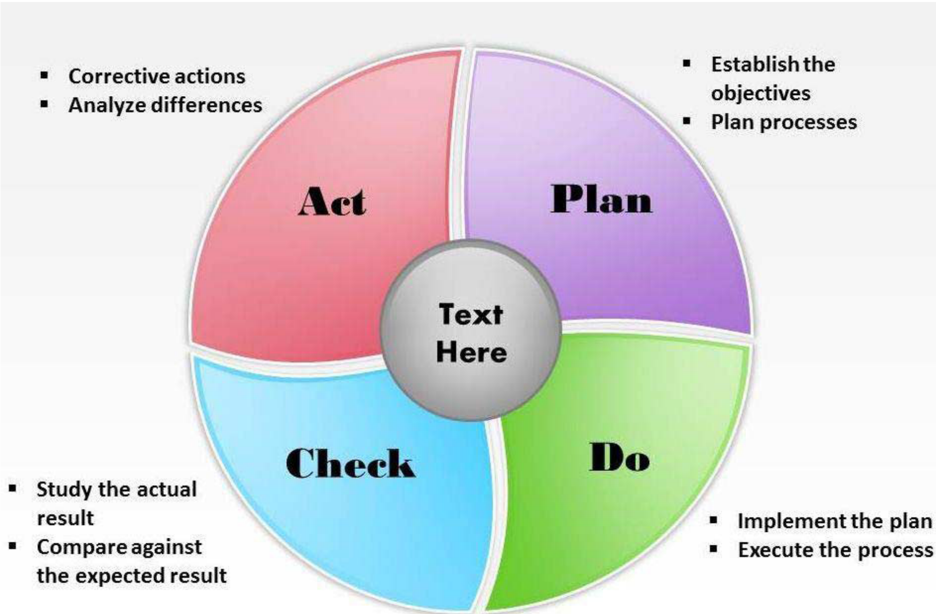

Figure 1. PDCA cycle.

WCM - World Class Manufacturing:

World Class Manufacturing is a set of techniques, concepts and principles for managing operational processes of a company [20]. The WCM model is the result of several activities used in the Japanese manufacturing industry after World War II. After an adaptation to Western context was first introduced in 1982 for several American companies [21]. This model is based on the TPS (Toyota Production System), Toyota production model, which originated through a different philosophy based on Henry Ford and Taylor assembly sequence, where its basic idea is to "do more with less" by eliminating losses and waste [20]. WCM is, in short, the pursuit of excellence by applying the methodologies and tools based on lean manufacturing, which is based on TPS [21]. This new paradigm is based on the analysis of practices implemented by Japanese, American and German companies, which had an outstanding performance at their industries [22] [21] [23].

With the evolution of this model, it allows the application of Just in time methods, Quality Control and Total Productive Maintenance which respectively are: every component that reaches the assembly line at the precise moment it is needed and only the quantity needed for assembly; methods and controls used to achieve the highest quality aimed at Zero Defect and maintenance as center of attention of the productive processes to aim at breaking Zero machines and avoiding unplanned production stops [20]. The main objective of the WCM is to always seek the continuous and rapid improvement in cost, quality, time of production and customer service, always running with all indicators seeking continuous improvement [3].

ISHIKAWA Diagram:

Founded in Tokyo in 1943 by Kaoru Ishikawa, diagram or fishbone chart as it is also known, it is a common technique used in the analysis of production processes with the main objective to identify the most influential factors causing an effect [12]. The initiation of the process [24] is the best time to use the diagram, so that effects of any kind are identified.

An example of the chart may be found at Figure 2.

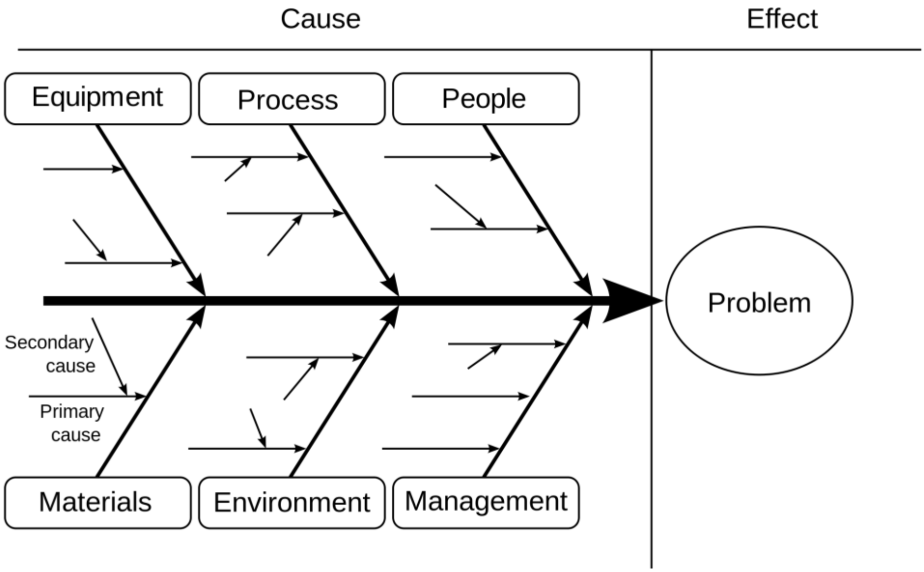

Figure 2. Cause-effect diagram.

2. Methodology

The technics and methods used for this work are mentioned as follows. The study was developed by observing some employees at working station and analyzing the results.

2.1. The Alpha Company Briefing

After two years of investments in technological interventions, Alpha Company launched in 2010 its production unit of medium engines in Latin America. Designed with the concept of lean production, it is a different plant, covering aspects such as ecology, quality, high-level professional staff, management, products and processes - with high automation index and high technology incorporated. The factory has four machining lines: block, crankshaft, connecting rod and head, and a total of 54 machines. One of its main advantages is the automation in the supply of machined the assembly line via gantries (supply by air). The technology allows, for example, the unit to operate without forklifts for supplying materials in the production process. The plant, located in the Metropolitan Region of Curitiba (Paraná – BR), is responsible for the manufacture of propellants family 1.6l 16v and 1.8l 16v, flex and gasoline. This production began in February 2010 with an initial capacity of 330,000 engines per year. The opening took place on the outcome of the acquisition of the former supplier of engines for vehicles such as the Gamma and Beta - the company under study in March 2008. Since then, the multinational made investments nearly to $ 95 million to make the plant even more modern and achieve a level of excellence in products and processes.

With the new plant, the company has increased its installed capacity in Mercosur at around 20%, reaching a production potential of 2.5 million propulsion systems per year. "Before the acquisition, the production of this plant was dedicated exclusively to export, which attests to the global character. Today, the company is ready to meet in addition to the Brazilian and South American market, the five continents within and outside the Group, which is a big step in the company's strategy "- said the Superintendent.

The assembly lines also have ultimate control equipment, to measurement and rating of 100% of machined parts, and model machines in Autonomous and Professional Maintenance, prepared with the most modern concepts of maintenance, aimed at breaking zero index. The excellence of machined parts is also ensured by a sequence of controls capable of ensuring compliance with the quality checks. The three assembly lines, comprising the pre assembling head, the main line and the finishing of the engine equipped with robots sub assembly bushings and 77 devices - 17 stations tests, 12 automatic stations 17 semiautomatic stations and 31 manual stations. These machines are capable of making cold tests with timing simulations, load and vibration, and sealing tests on 100% of the engines.

2.2. The Scenario

The case study for the application of the concepts mentioned [25], was the analysis of a job that allowed the fitting of parts outside the standard and the opportunity to improve its automation system, and the pressing of the spark plug wires. There was a possibility of non-standard parts assembly, inspection found the final assembly. The pressing force was applied according to the employee's strength, with variation depending on the physical fatigue, inattention, bad adjusted point of contact, among others. With this kind problem of risk was added a checkpoint operation generating a cost of approximately $ 3,400 year for the inspection of the quality of the final product, thus ensuring the quality of the final product.

In this case a physical force is required since the employee who operated had to hammer the spark plug wire by applying a force, and carried out this activity for an hour a day, for a total of 320 cycles per hour. The working station was already saturated by activities and the new engine entry, new components needed to be installed, requiring the desaturated station to receive the new product. The only activity that could be moved to another working station was spark plug pressing that allowed full automation of activity, reaching the zero defect in quality, zero ergonomics problems and the ability to get more parts for assembly on the job.

2.3. The Problem

The problem occurred during any shift and not at a specific time, being found in the final inspection. The inspection was done in one hundred percent of the parts through control but without any prior verification of control as error-proofing. The occurrence independently stemmed from the operator or at random shift, which can be linked to operator fatigue in the station as it requires a high physical exertion.

In Figure 3 you can see the problem with your defect and the reason for the same is generated, coming to the conclusion that the concept of the tool does not guarantee the strength, being totally dependent on the operator.

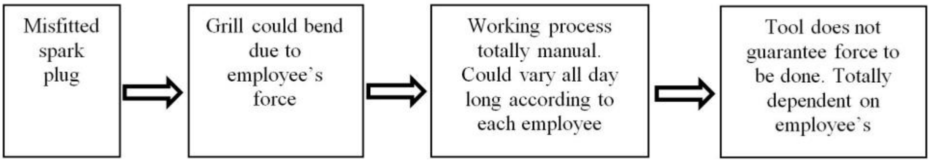

Figure 3. Problem analysis.

The operation is one hundred percent manual, making it difficult for the operator to follow the same level of application force and point of contact between the hammer and the spark plug wire.

By analyzing the problem in order to examine the failure mode and its possible causes, it was concluded that there was no standard for fixing the spark plug wires at the engine, as it varied with the strength each employee when performing the impact with the hammer.

Figure 4 shows the fitted and not fitted spark plugs after operation.

Figure 4. Spark plug fitted (left) and not fitted (right) according to method.

Source: Authors based on ALPHA Company.

It was added a checkpoint operation generating a cost of nearly $ 3,400 per year, for quality inspection.

By analyzing the problem in order to examine the failure mode and possible causes of it, concluding that there was no standard for fixing the spark plug wires at the engine, as it varied with the strength each employee when performing the impact with the hammer.

As there was no check point like error-proofing and the problem did not occur at a specific time, but throughout the work shift with all operators and spark plug wires , it was detected that it was linked to operator fatigue the high physical exertion , since the operation is done a hundred percent manual and difficult for the operator to follow the same level of force application and point of contact between the hammer and the spark plug wire.

Figure 5 shows the ergonomic effort during operation.

Figure 5. Ergonomic effort required by task.

Source: Authors based on ALPHA Company.

During 6 months of follow up there was found a series of misfitting spark plug wires results: 8; 3; 5; 5; 6 and 17 each corresponding month.

3. Implementation

The main purpose of this section is to inform how system was changed and improved from analysis to result.

3.1. Trouble Shooting

In order to solve this problem, it was applied the methodology of PDCA cycle and Kaizen getting results step by step until the full completion of the system itself, by using the specific form of the company in which the work was applied.

After analysis, it was carried out the design for process automation. For this, it was used a load dynamometer to determine the strength of pressing each spark plug wire, coming to the following results (average numbers):

Wire 1: 28.4 kgf/pressing Wire 2: 27.8 kgf/pressing

Wire 3: 26.8 kgf/pressing Wire 4: 29.3 kgf/pressing

To ensure that non-conforming parts could be produced by pressure drop in the compressed air network, was placed a pressure switch, as shown in Figure 6 to control the minimum and maximum pressure. If it is outside the specified limit, it will be presented a failure and the operation redone.

Figure 6. Pressure switch system.

Source: Authors based on ALPHA Company.

After this analysis, it was applied the methodologies of PDCA and Kaizen cycle up to step by step until its full completion, using the specific form of the company in which the work was applied and as a result, the project was carried out for process automation (Figure 7) and used a load dynamometer to determine the strength of pressing each spark plug wire.

Figure 7. Spark plug pressing device (left: off; right: on).

Source: Authors based on ALPHA Company.

4. Results and observations

The device is designed to have a quick construction, easy installation and low cost, with a view to autonomous maintenance. The device design has been thoroughly analyzed, reaching the improvement in pressing the cables, as was done manually by operators. With these assumptions, the company increased the quality of their product. According to the main idea, the spark plug wire pressing device was implemented without any restriction.

With the design of the automated spark plug wire pressing device it was possible to reduce the work station cycle time of 3.88 seconds total time ranging from 35.08 seconds to 31.2 after system modification (based on MTM - Methods Time Measurement). With the reduction in the post cycle time and the redistribution of activities, it was also obtained a better performance of employees.

With the implementation of spark plug wire pressing device there was a rearrengement in the layout of the line. With this change of layout it was possible to realize a gain of space in the line and a reduction of the activity that was previously performed to verify that the cables were pressed, i.e., the device now ensures hundred percent of pressing the cable, obtaining potential gain $ 3,400 per year.

It also had a gain in developing ergonomics, as from now on there is no longer required manual work where the operator hammered the spark plug wires.

Due to fatigue and change in employee strength, satisfactory quality could not be achieved, however, with this work, the operation guaranteed accuracy and constant force in all cables simultaneously presenting no risk any cables leave without being pressed correctly.

During the following months after implementation of the new device the system presented 2 defects in the first month, 2 in the second and ZERO during the whole period of eight months.

5. Considerations

By means of using the PDCA tool and KAIZEN methodology, it was possible to reach the expected result set at the beginning of the work, based on assumptions as quality and improvement of the working station. At the beginning of this work was possible to observe a fully manual station without standard for activity, with non-pattern pressing forces and point of contact, variables for each employee and by this study development, a desaturation of the job to get a new product from a new project.

With the modification of the process and the new method of pressing the spark plug wires, it was possible to eliminate defects and rework quality, obtaining a benefit of nearly $ 6,500 (six thousand five hundred dollars).

Finally it is possible to say that the main objectives have been achieved - to ensure the pressing of the spark plug wires to reach zero defects, reduced rework costs and engine maintenance of a fixing pattern for one hundred percent of the motors with increased quality and productivity of the production line and the desaturation of the working station for new operations.

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Part 12

Product Lifecycle Management

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Transdisciplinary Engineering: Crossing Boundaries
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Integrated Approach Bridging PLM, ERP, SCM in Automobile Industry

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Abstract. New Product Development (NDP) is a major source of competitive advantage to automobile manufacturers. More specifically, Product Lifecycle Management (PLM) has proven to have a positive impact on the effectiveness of the product development effort. One of the many reasons for that is the fact that PLM requires detailed attention to the constraints a firm will face, depending on the stage of the product. Widely accepted references outline the important of decision making in PLM. This trend is also is reinforced by the number of research projects in known, global centers of excellence in product development and innovation. Enterprise Resources Planning (ERP) approach is in the stake to supply the plan to best use of resources allocated to the project. Another revered trend is the idea of integrating the whole supply chain from a value-adding perspective. Thus, the Supply Chain Management (SCM) and Manufacuturing Engineering Systemas (MES) of current and new suppliers for newly developed parts or products are the key players for the competitiveness in the market. Conversely, strategies, methodologies, and PLM tools present themselves as agile, lean, safe yet collaborative approach to NPD. This paper presents an integration of ERP into PLM with a special emphasis on SCM. The automobile industry, as an example is to contextualize the discussion.

Keywords. product lifecycle management, business process, supply chain, enterprise competitivenes.

Introduction

Presently, several technologies applied to the generation of information are available providing more knowledge and opportunities to the modern enterprises. Some of main emerging technology [1] Executive Information Systems (EIS), Decision Supporting System (DSS), Enterprise Resources Planning (ERP) e Operational Information System (OIS). The author complement that these are considered technology because some way utilize the computer resources of hardware, software, telecommunication system and the management of information data.

1. The development of systems MRP/ MRPII to ERP

One conception, [2] that the software MRP (Material Requirement Planning) initially when introduced in the market in 1960, contemplated only the production modules,

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purchase and stock management, with more prominence in the material needs. From the first module, other modules emerged and incorporated to the system such as: capacity requirement estimation, shop floor control, purchase control among others, reaching this way the first stage of the evolution of the MRP system that called MRPII (Manufacturing Resources Planning).

This evolution followed the technology improvement until to reach the stage of ERP (Enterprise Resources Planning), system introduced aiming to provide total integration of business solutions, linking more areas and functional sectors in several dimensions in the enterprise: human resource, financial costs, sales, purchase, logistics, among others, aiming to keep aiming to keep competitiveness advantage [3].

1.1. ERP systems: introductory aspects and overall vision of its benefits to the enterprises

Presently the Integrated Entrepreneurial Management System (IERP) reached expressive level mainly from decade of 90´. In the context of the development of the ERP system, [4] explain that, in decades of 40´ and 50´, labor cost represented 60 to 70% of the final costs of the product. By the decade of 90´, the cost of raw material represented 60 to 70% of the final products cost which does not match with the practice to keep large stocks.

Authors [2] the ERP system provides solutions that benefit and better the efficiency, quality and productivity of the enterprise, raising the results the satisfaction of the clients. In this context, it is noteworthy that, the utilization of the modules is linked to the type of business and the specific needs of the enterprise, although, those inherent to the finance sector are considerably more utilized (Table 1).

Table 1. Modules of the ERP, adapted from [5].

Modules related to Operations and Supply Chain	Modules related to Finance/ Accountancy/Revenue Mgt.	Modules related to Human Resources Mgt.
Forecasting and sales analysis;	General accounting; Costs;	Personnel;
Bill of materials;	Bills to pay;	Payroll
Rough cut production/capacity plan; Materials planning;	Bills to receive; Revenues;	
Detailed capacity planning;	Revenue receipt;	
Purchase;	Revenue accounting;	
Fabrication control;	Cash management;	
Stock control;	Asset management;	
Engineering;	Orders management;	
Physical distribution;	Definition and management of the business processes.	
Transport management;		
Projects management;		
Support the repetitive production;		
Support the mgt. of production in processes;		
Support the programming with finite capacity of discrete production;		
Configuration of products.		

Through, the integrated ERP system, the enterprise can improve the performance in the business to derive countless other benefits, which are presented in the Table 2.

Table 2. Tangible and intangible benefits of the ERP systems, adapted from [2].

Tangible benefits	Intangible benefits
Reduction of stocks	Visibility of information
Reduction of personel	New processes and improvement
Improvement in the productivity	More quick attendance to client
Improvement in the management of orders	Standardization
Improvement in finance	Flexibility
Reduction of costs	Globalization
Improvement in the management of cash flow	Better performance in the business as whole
Increase of the profit	
Reduction of costs with transport and logistics	
Reduction of costs of the maintenance	

1.2. Main characteristics of the ERP system, factors that interfere in the implantation and changes caused in the organization

In this context, authors [6] state that the implantation of ERP system causes impact of extraordinary repercussion in the enterprise, such as: changes in the management models, change in the interaction among persons and groups, redefinition of the limits of authority and autonomy e alteration in the strategic processes of the organization.

In several cases of implementation, these systems were considered unsuitable by not achieve with success the target of the enterprise [7]. In the acuity of this issue, denoted that several factors interfere to obtain the successful implantation to derive desired benefits, therefore, it becomes necessary more broad analysis of these facts. This way, a wholesome aspect to the system to achieve effectively the organizations objectives would ripening and the preparation of the enterprise for a change defining clearly the needs and business objectives, enabling persons to face the behavior and technological challenges.

Systems as commercial package: the suppliers of the software had put effort to link their systems to specific market niches. The difficulty for the enterprises consists on the adequacy of the software to business processes. Usually, ERP systems offered in the market as closed commercial package, obliging the buyer entrepreneur the adequacy to the software. Is denoted that this is the marketing strategy of ERP, whereby such systems are not developed for the specific clients, aiming to attend generic requirements of major possible number of entrepreneurs, right to exploit the gain of scale in its development" [8].

Total integration of the sectors: this is positive factor of these systems, once the information present unique input, generating consistency, efficiency, thus offering reliability to the managers. Adding, the integration of departments/divisions of the enterprise facilitates technological updating and the reduction of costs [9].

Functionality adequacy: the acquisition of ERP system can generate two situations to the enterprise: first is the process to adequate the system to the organizational needs through parametrization; second is the process of personalization or customization, which consists in the adaptation of the system to the specific needs of the enterprise. In this case, other programs also should be integrated to ERP;

High costs: this considered as the main factors that obstruct the implantation of ERP system. The costs predominantly related to the infrastructure of hardware and software, consulting, training, contract of specialized personnel and other costs incurred in the change of the system. Likewise [10], declared that what denotes is the lack of planning, forecast the spending with customizations, that in consequence, end up generating costs that exceed the foreseen budget. Regarding to this fact, it appears that in several cases supplies do not offer support to the entrepreneur routine highly customized, competing equally to elevate the costs with the maintenance of the system [11].

Locating process: The ERP software developed in foreign countries can adequate to the reality of the host country. However, is crucial to analyze the risks and impacts of these changes. Corroborating this statement, authors [10] explained that the culture of the country and the government policies also influence the process of implementation, mainly when occur in different countries, thus affecting the configuration and maintenance of the software. Government policies, often imposes conditions that the software ERP is not adequate to solve the problem. The authors call this as “effects of the national culture” [10].

Updated version: offer the possibility of upgrades, that are improvements incorporated to the system, updating with new version to adequate the changes. This aspect has received critical of other authors, by claiming that there is difficulties in the flexibility of the system to adapt to the reality of the enterprise, to answer the variations and the growing of the business [12].

Alterations in the productive and administrative processes: this is the main of the system. The adaptation of the processes, so much productive, as well as administrative, aims to improve the relationship of enterprise with the system and vice-versa.

Impact over human resources: Given to the relevance of the human factor in the implantation of the ERP systems, it´s not possible to plan the system without considering the impact that will cause in the persons. More than the technological tool applied to better the work processes, the system calls the alteration in the profile of staff, requiring multidisciplinary knowledge and the predisposition to paradigm shift. Complementing, the author [4] states that the most difficult task is to integrate persons and different departments involved in the implementation of the system. This occurs because when deals with persons, normally exists the reaction behavior against the changes.

Difficulty to comply with the dead line and budgeting: This factor, according to authors [13] can occur due to the frequent change of personnel in the enterprise, lack of training, resistance to use the program, quality of the contracted consultancy, technical limitations of the system itself, and affinity of the ERP with other existing systems in the enterprise. There is still, other factors such as time, uncertainty, inadequacy to the needs of the users and the deficiency in the definition of functional requirements, that also cooperate to make difficult the implantation process [4].

Analyzing what presented towards ERP systems, denote that these systems present for the enterprises two opposite situations: first regarding to the benefits and impacts that cause; second the difficult of implantation. For that reason, the discussions towards investments, complexity of the system, functionality and adaptability outcrop increasingly in the enterprises.

2. Product lifecycle management for innovative and competitive business

Product lifecycle management (PLM) is the process of managing the whole life cycle of a product starting from generating an idea, concept description, business analyzes, product design and solution architecture and technical implementation, to the successful entrance to the market, service, maintenance and product improvement.

At present, a wide range of stakeholders including consumers, regulators, shareholders and public bodies aredemanding that companies address product management through all life cycle in a more comprehensive and sustainable way. However, even if a company actually wishes innovate its processes for improving the way to account for project management, it will face relevant difficulties to deal with different guidelines, tools and methods currently addressing the matter from various points of view. The purpose of this paper is to review literature on PLM from an operational point of view with the objective to help companies to answer to the main market needs.

The goal here is to enable product development teams and manufacturing teams to work together as early in the product lifecycle as possible to: minimizing production cost, improving product quality, delivering more reliable products, providing easier to service products, driving “green” initiatives that facilitate a sustainable environment.

PLM enables the kind of convergence that enterprise resource planning (ERP) and customer relationship management (CRM) prompted in the past. In the early 90s, ERP unified finance, HR, manufacturing and warehouse systems. A decade later, CRM brought call center and sales force automation together. Through PLM, the products are a path to innovation, industry leadership, and topline growth [14], [15] and [16].

2.1. Technical requirements

Due to cost pressure, producers are forced to standardize and introduce standard components. The extended time in use of plants, along with the usage of standard components, requires adapted lifecycle management strategies. As a result, there are high compatibility requirements such as service requirements.

Because of the short times in use, producers of automation components traditionally offered standard services. However, because the times in use are increasing, producers of automation components can now offer continuous service extending over a number of years. The re-use of systems at other locations, or in manufacturing facilities for new models, applies to all automation components, including systems such as robots. Additionally, a number of producers offer refurbishment and reprocessing of used products as a service.

2.2. Industry-specific economic aspects

In automobile manufacturing, the initial investment for a plant or a production line is the financial focal point. However, the life-cycle-costs are becoming increasingly important in the planning phase. This also leads to employee-related cost savings due to the capability to deploy employees across different plants. Additionally, standard components can typically be sourced more quickly from manufacturers.

Previously, different variants of a specific vehicle model were manufactured on several production lines. Presently, however, these variants are produced on only one single manufacturing line. As a result, automobile manufacturing is now characterized by very flexible manufacturing processes and high throughput rates. Another cost saving option is the use of modular- and platform-concepts.

The fact that these platforms are used for multiple applications ensures better manufacturing capacity utilization and thereby lower production costs. When considering costs, investments in modernization are assessed in comparison to the increasing life-cycle-costs of the existing system. The reuse of systems can lead to reductions of investment costs of up to 40 % [17].

Cost savings achieved by increasing energy efficiency and the conservation of resources such as gas, water and electrical energy are topics that are increasingly high on today's agendas. Under the heading of "intelligent load management for plant sections" improvements in energy efficiency are addressed. One such option is completely shutting down plant sections when they are not required.

PLM is an integrated, information-driven strategy that speeds the innovation and launch of successful products, built on a common platform that serves as a single repository of all product-related knowledge, data, and processes. PLM is the process of managing the whole life cycle of a product starting from generating an idea, concept description, business analyzes, product design and solution architecture, technical implementation and product testing, to the successful entrance to the market, service, maintenance and product improvement.

In the current economic climate, addressing global business challenges is the top priority of most medium and large enterprises. Whether they want to expand their customer base in new markets, or to leverage more cost competitive resources, conducting their business globally is a necessity [15]. To sustain an advantage, they have to overcome the challenges of a dispersed organization, while still empowering individual team members to excel.

PLM concept offers comprehensive solutions to help enterprises address their challenges and create competitive advantage. Five areas where medium and large enterprise should have achieved success include: Managing new product introduction, to create a winning product portfolio; Achieving concurrent engineering globally, to be faster to market; Creating platforms for reuse, to reduce cost and speed product customization; Managing product and manufacturing complexity; Supporting products currently in-service, to ensure they are available for use at minimum cost.

2.3. PLM metrics development process

The questions often asked in business and commerce are how well are done, and how do know what the work should be done? Find out the metrics process to measure what is meaningful is important in this issue [16]. The way to find out answers to these questions is to measure the outcomes of the processes involved. As PLM transforms the way enterprises do business, it is important to understand how well they are doing currently that need to be measured. The measurement of PLM requires the development of metrics for the process which is essential that what is identified as a metric is relevant, appropriate and important. The metrics can be applied at various levels of complexity as the objective of the metrics development process is to identify, develop, and articulate metrics that would help enterprises implementing PLM determine the extent to which their efforts are paying off. The PLM assessment process model shown at the Figure 1, conceptually presents the metrics development process.

Level 1: At this level, the question is whether the enterprise is applying appropriate resources to the PLM process;

Level 2: The metrics are used to determine if the appropriate PLM processes were implemented;

Level 3: Focuses on customers being reached;

Level 4: Metrics to examine the efficiency whether the outputs meet the needs of customers are being met;

Level 5: Effectiveness, if desirable results are being achieved;

Level 6: Metrics are used to measure the impact of the implementation of PLM by measuring the extent to which procedures and controls have been integrated and the return on investment. This level metrics are the most complex and difficult to measure. These include waste reduction, innovation or new products, continuous improvement, and sustainable green manufacturing.

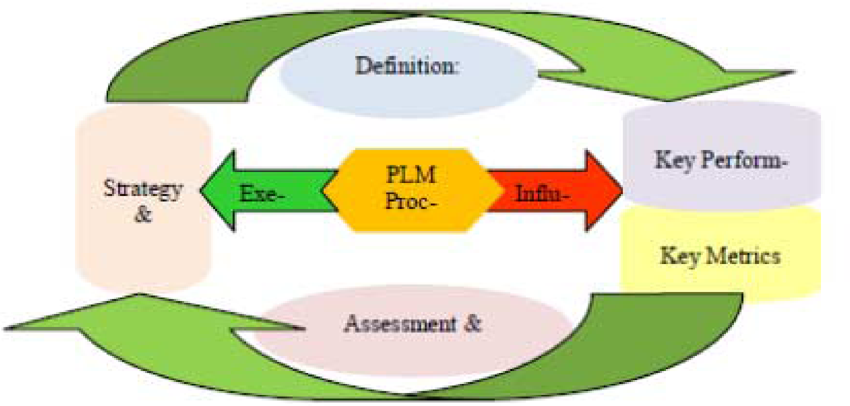

Figure 1. PLM Assessment Process Model [18]

2.4. PLM business value

PLM business value is perceivable when the enterprise implements this concept in work that can move forward strategically while achieving sound results and enable to establish a platform for innovation. When the enterprise addresses specific business issues to build a solid foundation for future success through PLM platform, it will be able to realize measurable innovation benefits both immediately and over the long term as can be seen on the Figure 2.

Traditionally the business practice by enterprises is to bring their products to market in time-consuming serial processes that delayed the participation of downstream contributors. The participation of suppliers, manufacturing experts and after sale service or maintenance providers were aside. PLM enables to allow the enterprise to execute as many tasks as possible in parallel processes to streamline and collapse critical stages in the product lifecycle.

Furthermore, the PLM allows to deliver aligned and accurately highly synchronized product knowledge to multiple disciplines early in product lifecycle. Avoids the cost and scheduling impact that comes when late suggestions and unexpected concerns arise from downstream players. It enables the enterprise to beat the competition launching the innovative product content that carries advantages and drives early sales for profit.

Figure 2. PLM business value [18].

2.5. Increase profitable growth

In the world class manufacturing scenario the cross-functional teams collaborate in real time on the development process, each contributing their unique experience and perspective for quality and cost effectiveness.

Lessons learned and the knowledge acquired are captured for potential re-use in a process of continual innovation, facilitating the mass customization delivering the product offerings that satisfy the needs of individual customers and targeted market segments. It combines the advantages of configuration of option and variant management. These capabilities allow the enterprise to perform portfolio planning in as flexible and continuous process as possible to fulfill the customer requirements.

2.6. Integrating enterprise solutions

Understanding the value and function of key technologies and how they interface each other flowing smoothly is a matter how the stakeholders enterprises are structured using updated information technlogy effectively. Supply chain management practices are paramount to connect either in house or outsource manufacturing engineering systems. The ERP, as a transaction driven sector, all involved sectors should operate synchronized way to avoid any interruption in the communication system. Likewise, the PLM sector is composed by the driven sector, so that must be provided by a buffer of information concerned modern product development process, manufacturing and portfolio management process. The SCM and the MES are the event driven sectors, such that must guarantee the real time data collection, quality reliability, logistics and delivery.

2.7. Work package generation

PLM as new approach provides a single source of truth of intellectual property, thus production planners have work packages that contain all necessary information including but not limited to: bill of material information, electronically validated process steps, associated resources, and equipment list.

To maximize efficiency and the enterprise performance by leveraging the relationship and data flow throughout between PLM, MES and ERP, those approaches are integrated as shown in the Figure 3.

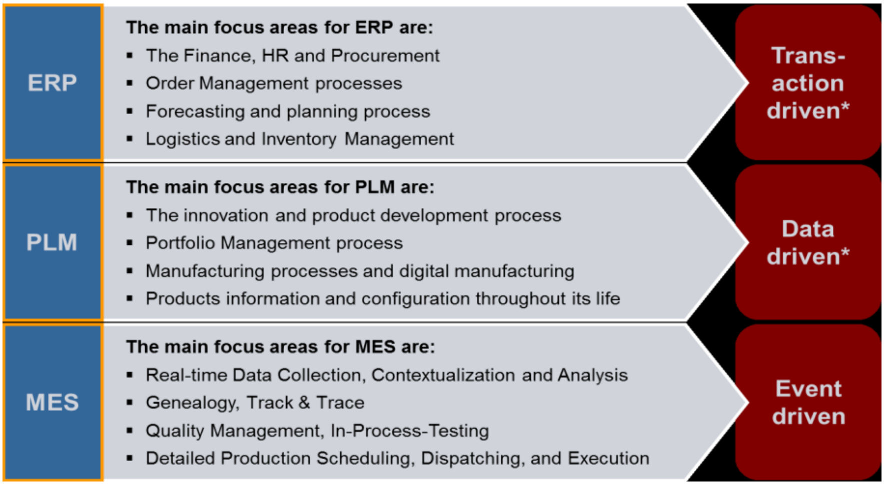

Figure 3. Integrating enterprise solutions [19].

By implementing enterprise information systems to develop more efficient facilities and adopt new, innovative ways to capture and execute manufacturing and maintenance contracts, the PLM provides a comprehensive collaboration foundation by the closed loop PLM-MES-ERP and by the adoption of technology to support an integrated business approach to improve the communication tasks accurately.

3. Why is PLM a necessity in automotive industry?

Reasons why is PLM a necessity in automotive industry can have several answers:

There are always many new products being developed simultaneously in the automotive industry with large number of designs being created, reviewed, modified and approved [20].

Due to the competitive nature of the automotive sector, the products have to excel in terms of quality, cost and usability. Ability to quick customization of automobile features is an essential part of the business practice as the smallest error can mean a huge production, capital and brand image loss.

Proper coordination between the designers, engineers and production units in the assembly line is a must as the collaboration across the enterprise helps catch the errors and rectify at the designing phase itself. This saves the cost and effort of repetitive manufacture of defective parts.

4. Consclusion

Competitive advantage to automobile manufacturers is alwais dependent on new product development as a majojor source. Product lifecycle management has proven to have a positive impact on the effectiveness of the product development effort.

To achieve a successful enterprise endeavour the ERP approach is in the stake to supply the plan the best use of resources allocated to the project.

The value adding perspective of whole supply chain management and manufacturing engineering systems for newly developed parts are the key players for the competitiveness.

This paper presented an integration of ERP into PLM with a special emphasis on SCM and MES. The automobile industry, as an example is to contextualize the discussion for further studies.

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Diagnostic Techniques in Project Management

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Abstract. Project management practices are critical to improve quality and success of the results. One of the main challenges for project professionals is to identify the characteristics of each project in order to choose a more suitable set of practices and tools that will contribute to greater management performance. In this article, a systematic literature review (SLR) was conducted to identify studies related to diagnose techniques in the project management. Through this review, 22 articles were selected. This paper presents a set of diagnostic tools in order to assist in solving this challenge. Developing a better understanding on how to apply these diagnostic tools, professionals will be able to select management practices that are better suited for different types of projects in their organizations. One main restriction found across the diagnostic tools identified is that they do not indicate how to improve project management performance. From the theory standpoint, scholars could compare how project performance is influenced by different management practices and their combinations.

Keywords. Diagnostic tool, agile project management, hybrid project management, project management.

Introduction

There are different management approaches in the project management theory, including agile and traditional. The traditional or waterfall management approach, is based on methods and practices that follow a sequential series of steps, starting with the definition of requeriments, defining solutions, developing, testing, and delivering [1]. The scope of the project is well defined, the problem is clear, the planning approach follows a detailed process upfront and is minimally revised during the phases, the development is sequencial, driven by task dependencies and critical path, and changes are avoided [2],[3],[4],[5],[6].

There is a lot of criticism from project management practitioners regarding the use of traditional approach in more dynamic and innovative project environment. The answer was the appearance of new theories focused on innovative projects, involving a set of practices, tools and techniques named "agile project management" (APM). Innovative projects are characterized by dynamic, fast-changing environments, where there are constant changes in requirements, uncertaints caused by unknown risks, due to the degree of novelty of the tasks and requirements, causing project conditions never

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faced by the project team before [7]. The main difference, therefore, could be the development of the team's agility and flexibility, which relies on the tacit knowledge of the team members, rather than focusing on creating lots of documentation [2]. It is during the execution of the project that critical decisions are made, that will result in the project success or failure [8].

One potential solution that has been observed in many industry sectors, is the idea of combining management practices from different approaches. The main objective is to use the "best" part or practices from different approaches to improve performance and ultimately have better project results and success. Several authors have dedicated effort to explore the combination of practices and tools in the project environment [9 - 15].

The main challenge for practitioners and scholars is to diagnose what is the appropriate condition to apply a particular approach or combine them, then what practices, techniques and tools are more favorable to use according to a project context and characteristics. One potential solution could be the development of diagnostic methods. This paper investigates the diagnostic techniques in the literature and how they can support in this problem solution, through a systematic literature review.

1. Diagnosis in the field of project management

According to McCulloch and Cronshaw [16] in the organizational improvement perspective, the diagnostics development are highly desirable, if not essential for the development, change and intervention of informed and effective organizations. Diagnoses contribute in the process of improvement, because organizations exist as entities that need to be examined before receiving recommendations for actions [17].

The term "Diagnostic" can be found in several areas of knowledge, as shown in Table 1.

Table 1. The term Diagnostic in different areas of knowledge.

Knowledge area	Goal
Medical	Provides information about the conditions of a patient, orientate patient care through the information analyzed and understand the disease mechanism.
Organizational	Analyzes the organizational environment, identify the organization needs and involves relevant issues to the company, having tactical, strategic and operational consequences.
Environmental	Analyzes the environmental factors of a certain area (country, State, watershed, municipality) to analyze and raise the main elements of the physical, biotic and socioeconomic environment subject to changes with the implementation of an enterprise.
Social	Understand the society reality by identifying and classifying their needs and major problems observed.

It can be concluded that a diagnostic refers to the action and the effect of diagnosing, i.e., collect data and analyze it to evaluate a particular problem. In the project management perspective, diagnostics methods aim to identify characteristics and dysfunctions that may affect the project management performance.

2. Diagnostic tools in project management

The term "tool" comes from the Latin and refers to an instrument used in performing an activity, a job. In addition to this concept related to physical objects, the term "tool" can be related to any procedure which improves and facilitate the ability to perform a specific activity, such as Microsoft Project[2].Thus, the tools are a mean to facilitate and improve the performance of an activity.

In this paper, a tool is defined according to the Project Management Institute (PMI) that describes tool such as: "Something tangible, such as a template or software program, used in performing an activity to produce a product or result" [18].

Diagnostic tool in project management can be described as something tangible used to obtain knowledge about a particular problem, analyzing its characteristics, composition, behavior, or nature, in order to evaluate it and assist in solving different types of issues.

Diagnostic tools can be used to identify project characteristics and environment context factors in order to choose the more appropriate management approach. However, several factors need to be considered in order to identify dysfunctions in projects that are in progress and propose solutions to improve project quality.

An example of a tool to diagnose project characteristics and contextual factors is the Diamond Approach proposed by Shenhar and Dvir [5], which is discussed in section 4, applied to the project of the World Trade Center (WTC). Through the diagnosis, the authors analyzed the particularities of the project and made several considerations regarding its management approach.

3. Research Method

A well-made, effective literature review provides the researcher a solid theoretical basis for the subject and proposed work. Defining a systematic method to search, select and analyze the results will contribute to have a more reliable results and overview of the current "state of art" regarding a specific research topic or area [19].

This study is based on a systematic literature review, which encompasses the process of selecting, understanding, analyzing, synthesizing and evaluating a set of scientific articles with the purpose of creating a scientific-theoretical basis (State of art) on a given topic or subject [19].

The SLR framework used in this study has 3 main phases (input, processing and output). These phases are organized into15 steps (Figure 1).

In the first phase the research problem needs to be clearly and accurately defined. Then, the researcher defines the SLR goals, which should be aligned with the research objectives. Then the primary sources of research are selected (e.g., articles, journals or databases) in order to determine the keywords, authors and relevant studies. Next, the search strings that will be used in databases are defined. It is important to adjust the strings to meet each search engine characteristics and features and ensure that relevant studies will be identified. The inclusion criteria of the articles are defined based on the research objectives. The qualification criteria are critical to evaluate the relevancy of the studies found during the search. The definition of the search method and tools

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[2] It is a software program, developed and sold by Microsoft, which is designed to assist in the project and portfolio management.

includes the definition of how the search will be performed, how the results will be documented, and so on. The last step of the first phase is the definition of the SLR schedule to help the researcher control and search progress and results.

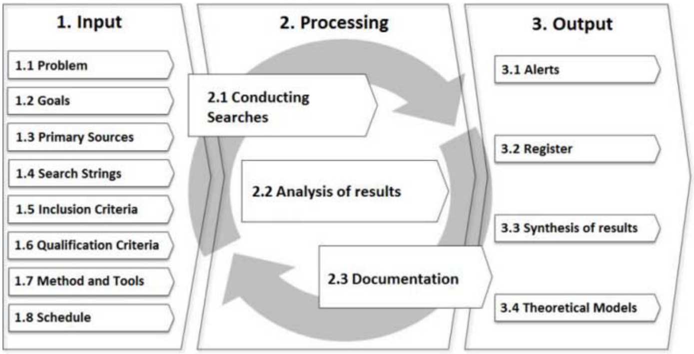


Figure 1. Model for the systematic literature review development [19] (Translated by the author).

In the second phase (Figure 2), the first step involves the search for periodicals, in order to create a list of the most relevant periodicals to the research, based on the primary sources. The search is performed using the previously defined strings. Then the results are submitted to multiple filters. The first filter includes reading of the title, abstract and keywords, which must be in accordance with those used in search strings. The second filter involves reading the introduction and conclusion sections of the article. The third filter consists of a complete reading of the text. It is also recommended to perform cross-search cycles (based on the reference list of articles found in the selected studies in filter 3) to identify relevant studies that were not found during the database screening process in the periodicals and other databases.

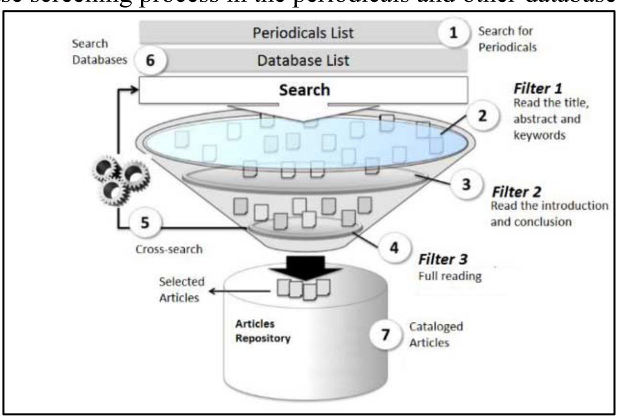


Figure 2. Iterative procedure of processing phase [19] (adapted and translated by the author).

The last phase of the SLR is to create citation alerts using keywords in the relevant databases and periodicals identified during the SLR in order to keep tracking of newly published articles. Articles that were reviewed and selected in the the third filter were included in the repository. Finally, the results are synthesized and the research questions are refined, hypotheses identified and theoretical models are built to support the research development.

The searches that support this study were conducted in the databases Web of Science® and Google Scholar, in the period between October/15 and November/15. The adopted search string is described as follows: "Diagnostic" or "Diagnosis" or "health check" AND "Tool" or "Instrument" or "Test" AND "Project" or "Project performance" or "Engineering project management" or "Project assessment" or "Project management".

The search resulted in 965 articles. During the filtering process, many articles did not come through and were excluded from the database. The set of criteria used to select articles for this study is as follows:

- Presents a model, method, tool or proposals for project diagnostics;
- Describe the development form of diagnostic methods;
- Involve areas of knowledge related to the project management topic.

The 965 articles had their titles and keywordsanalyzed based on these criteria. A sample of 22 articles were identified and submitted to the reading filters. This resulted in 6 articles that were considered aligned with the SLR objectives and were selected for a full reading. These articles were read, analyzed, catalogued and stored in a bibliography management software. From this analysis, it was performed a cross-search in order to identify relevant works that were not previously identified using the search string. Thus, a total of 16 additional studies were identified, summing up 22 articles considered relevant to this study. The results of the systematic literature review are described in the following section.

4. Results

The result of this study consists on the set of diagnostic tools identified in the project management literature. Table 2 shows the list of tools found in the SLR process, as well as their characteristics and objectives.

Through the analysis of Boehm and Turner [3] proposal, we can conclude that professionals carry out an assessment of what is the best approach to be used in a particular project, creating an overall strategy for being implemented, constantly monitored and evaluated. However, the work presented by the authors have as focus the software development, not involving other areas, influencing on the adopted dimensions. The authors do not discuss how to manage the software development project, once adopted a combination of approaches.

In the Wysocki [6] proposal, it is clear that the author focuses the software development projects, not incorporating other areas in their work. The tool presented by the author does not explain why those dimensions were adopted to differentiate the types of project management approaches. Another highlight is that the author does not use the term "agile project management" and does not address a combination of flexible and disciplined practices.

Table 2. Synthesis of existing diagnostic tools in project management.

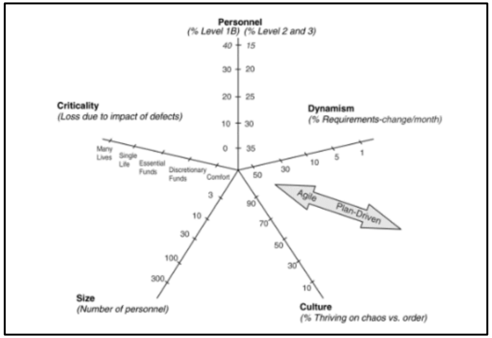
<table>
<tr><th>Diagnostic Tools</th><th>Graphical Representation</th><th>Goal</th><th>Dimensions Analyzed</th></tr>
<tr><td>Risk Approach [3]</td><td>

Figure 3. Risk Approach [3].</td><td>The authors present a risk-based approach to structuring the projects, incorporating agile and traditional practices, depending on the project needs.</td><td>The authors use a classification schema containing five dimensions, which includes conditions where agile and traditional methods are more likely to be successful:

People: consists of the different skills required to manage projects;

Dynamism: consists on the percentage variation of requirements per month;

Culture: analyzes if the organizational culture has well defined rules and procedures or provides greater freedom for those involved;

Size: number of people involved in carrying out the project; and

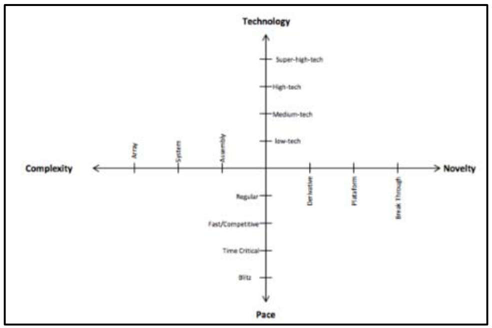
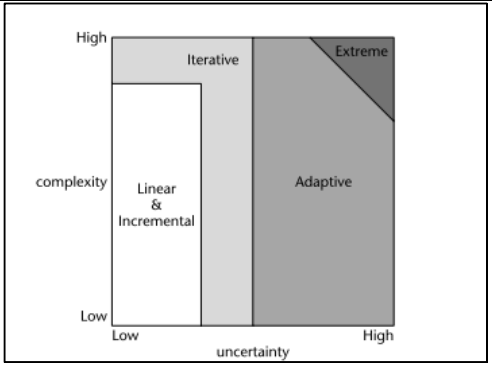
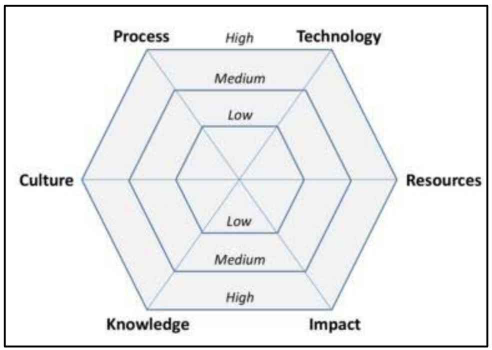
Citicality: evaluates the critical level of the project, loss due to the impact os defects.</td></tr>
<tr><td>Diamond Approach [5]</td><td>

Figure 4. Diamond Approach [5].</td><td>The authors address that a single management style does not fit in all projects, claiming that each project is unique, therefore, must take into account the project characteristics in order to adapt the management form.</td><td>The model deals with the variability of the projects, based on four dimensions:
Novelty: evaluates how new the product is for the market and its users. This dimension represents the extent to which customers are familiar with this type of product, how to use it, and its benefits. Includes three levels: derivative, platform and breakthrough;
Technology: measures the level of technology used in the project and the Organization's knowledge about this technology, encompassing four levels: super-high-tech, high-tech, medium-tech and low-tech;
Complexity: assesses the complexity of the project, it's defined using a hierarchical structure of systems and subsystems. Three levels are included in the dimension complexity: assembly, system and array; and
Pace: evaluates the time available for the project development. Four levels are part of this dimension: regular, fast/competitive, time-critical and blitz.</td></tr>
</table>

Table 2. (Continuation).

Diagnostic Tools	**Graphical Representation**	**Goal**	**Dimensions Analyzed**
Software Development Project Management [6]	 **Figure 5.** Panorama of the SDPM [6].	The authors proposed a tool towards the integration of project management with software development for professionals in order that they learn about the best practices to support their projects.	The author presents a schema involving two dimensions to be considered: Complexity and Uncertainty. Through the analysis of these dimensions, five types of approaches to software development are presented: linear, incremental, iterative, adaptive and extreme. Each of the five types of software development approaches can be supported by consistent project management approaches.
Diagnostic Framework and Health Check Tool for Projects [20]	 **Figure 6.** Framework for assessing the "health" of the projects [20].	The authors developed a diagnostic tool to assess the health of a project organization. The tool is constituted by an integrated view of project systems.	The tool involves the following dimensions: Processes: encompasses the adoption and implementation of structured procedures and processes-oriented guidelines throughout the project life cycle; Technology: evaluates the information and communication technologies (ICT), and the specific technologies to the project; Resources: involves the necessary infrastructure for the full development of the project, as well as the personnel involved; Impact: involves the general results of the project, including the initial project outputs and the wide range of benefits arising from the delivery of the project; Knowledge: involves data management activities and information that enable the effectiveness of the projects, as well as the planning and control of these; and Culture: relates to the standards of work and behavior patterns, as well as the levels of trust and reciprocity, both in relation to the benefits and risks of the main project stakeholders.

In the Diamond Approach proposed by Shenhar and Dvir [5], each of the dimensions, as well as their respective levels, affects how project management should be conducted. The authors present a graphical tool to demonstrate the gaps between how a project should be managed and how it is currently being managed. They indicate four dimensions and their levels, but not explain how, where or even why they choose such dimensions to be used in the diagnosis.

The Kennedy and Philbin [20] tool aims to contribute on the project performance through the analysis of its "health." However, the authors do not make clear the difference of levels (high, medium and low) presented in the tool and do not explain their relationship with the way in which the project is managed. There is a certain subjectivism on the routes to be followed after using the proposed tool.

We conclude that most of them do not explain about the analysis dimensions choice, as were developed and how they are different in relation to other criteria. Without enough robust constructs to identify the characteristics of the project environment and practices, it will not be possible to perform an analysis to identify the appropriate set of practices, tools and techniques to meet the project needs.

Other restriction found through this research, was the tools limitation to indicate which actions should be carried out after the diagnostic, which may be a challenge for the professionals, given the large number of practices, techniques and tools that can be used.

5. Conclusion

This article presents a set of diagnostic models in project management theory. The result was obtained through a systematic literature review and it shows that there are a few diagnostic methods focused on project management, noting a lack of studies focused on this theme.

The article raised important information about existing forms of diagnosis and the relationship of these diagnoses with project management approaches. The present tools evaluate the characteristics of a project based on the criteria such as personal, dynamism, size, culture, criticality, uncertainty, complexity, novelty, technology, resources, process, impact and knowledge. Although many of these criteria reach the proposal to carry out an analysis of the project characteristics, most of them do not explain why it's used, how they were developed or even how they are different in relation to other criteria, occurring a certain subjectivism.

The tools do not provide patterns or guidelines to interpret the results as common in otherwise organizational diagnosis instruments. Regular instruments in areas as cultural organization, organization climate is frequent the association of the diagnosis tool with guidelines or recommendations for the non-specialist professional. For example, if the result of the diagnosis showed that the project involves a high degree of innovation with many uncertainties and geographically distributed teams, the instrument could indicate a set of most recommended project management practices.

As a future study, we recommend the relationship analysis between the results from the diagnostic and the existing practices in the project management area, linking the best ones for a particular project. The hybrid approach can be involved in this process. Then, the next step would be an observation of this study in real cases.

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Transdisciplinary Engineering: Crossing Boundaries
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T-PROST: A Transdisciplinary Process Oriented Framework to Support the Product Design Phase in Systems Concurrent Engineering

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Abstract. The objective of this work is to present and to discuss the potentialities of a transdisciplinary process modeling methodology, which has been named T-PROST Framework, to support the product design phase processes (production and management) in the systems concurrent engineering lifecycle. The methodology consists in creating a conceptual reference model of the systems concurrent engineering lifecycle processes and to transform it into specialised models of the areas of (Model Based) Systems Engineering, Project Management, Business Process Management and Simulation Modeling. The main benefits generated by the approach are derived from: The systematisation of the model development, encompassing both the systems engineering processes and their management; The use of the T-ProST Framework for model implementation and analysis, based on the simultaneous use of diverse disciplines and their respective methodologies and tools; The joint assessment of the specialised models created to provide better solutions and to improve project development. The T-ProST Framework can be used for the implementation of generic environments, made by the ensemble of applications implemented with the specialised tools used in the diverse disciplines. These generic environments can be used to perform product lifecycle management by organisations conducting short lifecycle project developments, characterised by low and mid-level complexity scopes submitted to severe time and budgetary constraints, as an alternative to the use of complex, expensive and difficult to configure proprietary systems existing on the market.

Keywords. Systems Engineering, Project Management, Business Process Management, Simulation, Transdiciplinary Process Modeling, Product Lifecycle Management

Introduction

Transdisciplinary Process Science and Technology (T-ProST) [1,2] is a term used in this work to designate a holistic view, which consists of the integration of various disciplines that deal with complex discrete event process models: (Model Based) Systems (Concurrent) Engineering (SE) [3,4], Project Management (PM) [5], Business Process Management (BPM) [6,7], and Simulation Modeling (SIM) [8,9,10].

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The general goal of the research endeavors on T-ProST has a wide scope and very ambitious nature: to develop a mature and comprehensive transdisciplinary process modeling methodology and to design and implement its integrated supporting environment for conducting studies of a large category of complex discrete event process problems in order to achieve better and integrated solutions. The problem domain covered by T-ProST is essentially the same one covered by discrete event process modeling and simulation procedures based on modeling representations, such as Activity Cycle Diagrams (ACD) [8], Role Activity Diagrams (RAD) [11] and Workflow Diagrams (Workflows) [12].

The main difference and original contribution between the use of the T-ProST Framework and that of the traditional use of its component disciplines is the creation of a transdisciplinary process model and its use as a common basis for the development of their individual specialised process models. This is done by conducting a systematic modeling procedure designated as Conceptual or Reference Modeling and making use of a graphical notation denominated Unified Lifecycle Modeling Diagrams (ULMD), an innovative diagramming technique originated from a fusion of the aforementioned graphical representations [1,2].

This work presents the T-ProST approach as a totally integrated application of their individual methodologies and techniques, originated from their autonomous component disciplines, to the design phase of the SE lifecycle. The limitation of the scope to the design phase of the SE lifecycle in order to explain the T-ProST approach was made for demonstration purpose only. In fact, it can be applied to any category of complex discrete event process that can be dealt with the Unified Lifecycle Modeling Diagrams (ULMD) notation and it is intended to be scalable and capable of being used in a wider context, covering the whole organisation´s business process management.

The rest of this work is structured according to the following. Section 1 defines some fundamentals concepts used in T-ProST. Section 2 describes the methodology and its application. Section 3 identifies the problem and sets the overall scope of the research. Section 4 presents the conceptual modeling phase and the resulting reference meta-model. Section 5 refers to the use of the methodology to create basic or generic PLM environments, made by the ensemble of applications resulting from the implementation of the speciliased models, making use of the autonomous disciplines and their supporting tools. Section 6 makes some considerations on T-ProST´s domain of applicability and the benefits and limitations of the methodology. Finally, the Section 7 presents the conclusions.

1. Fundamentals of the Methodology

The most fundamental and distinctive concepts in T-ProST are those of the transdisciplinary reference process model and its specific notation, denominated ULMD [1,2]. The reference process model in ULMD describes the system´s lifecycle process in its essential structural and dynamical features, with the special purpose of serving as a common basis for the development of the additional specialised models to be implemented in each of the autonomous component disciplines ofT-PROST.

The format of the modeling notation resembles very much that of the basic set of BPMN [13] icons with a few extensions and one could question the need for "yet another type of process modeling notation or graphical diagrams". In fact, BPMN is widely used and supported by large communities, becoming the "de facto" notation for creating models to be converted into specific proprietary notations and implemented in a variety of proprietary tools offered by different systems´ manufacturers.

The use of the ULMD notation, however, is just a first step (the conceptual modeling phase) of a gradual modeling process and one can state that some semantic characteristics of ULMD are non-existent in any of the traditional graphical or textual process model representations, such as ACD, RAD, Workflows or even BPMN. These characteristics turn out to be essential for the type of logic and knowledge represented in the reference model.

The ULMD distinctive features start with its high level of abstraction and minimalism, comprising only a dozen of different symbols for expressing the complete structural and dynamics of the agents´ lifecycles as concurrent processes. The diagram logic expresses all-in-one: the hierarchical process decomposition, the variety of agents and messages and their process control flows, the agents´ lifecycles or roles and the interactions among them. The diagrams are created in the form of encapsulated modules, which can be displaced in frames or swimming lanes and pools, describing from a very simple process (task) to a very complex one (macroprocess).

Underlying all these characteristics, some of which could still be stated in regard to Business Process Management Notation (BPMN), there is an unequalled feature that differentiates ULMD from all other types of existing process modeling diagrams. They are not about pure logical operations and control flows (flowcharts), they are essentially about real time consuming transformation activities performed by real entities and messages (objects) exchanged between them.

The links correspond to real entities flowing along their lifecycle (solid lines) or objects (dotted lines) exchanged between the activities, both used as inputs to other activities. Each class of entity has its specific process lifecycle, and they interact to perform their time consuming common activities, which get into a halt until all required inputs (entities and/or objects) are available and the additional internal initial conditions for their execution are satisfied. One special type of condition is external and it is depicted graphically, named triggering mechanism.

The control flows are always associated with some type of entity, resource, object or triggering mechanism, and they reactivate the processes in a hold at a particular point in time and location, making it progress through its complete lifecycle.

2. The T-PROST Framework

A T-ProST study is performed making use of a framework (T-ProST Framework) [1,2], consisting of three elements, which constitute the pillars of the methodology: 1) Knowledge Structure, made by the transdisciplinary hierarchical process model created (conceptual or reference model) and all additional information on the system being studied; 2) Implementation Method, which is the method used for the evolution of the models along their respective lifecycles; 3) Supporting Environment, which is made by the integrated set of tools used and their applications.

Figure 1 presents the T-ProST approach described as macro-processes and their respective component activities. The first column shows the Implementation Method or Unified Lifecycle Modeling procedure used to create the specialised models and evolve them along their lifecycles.

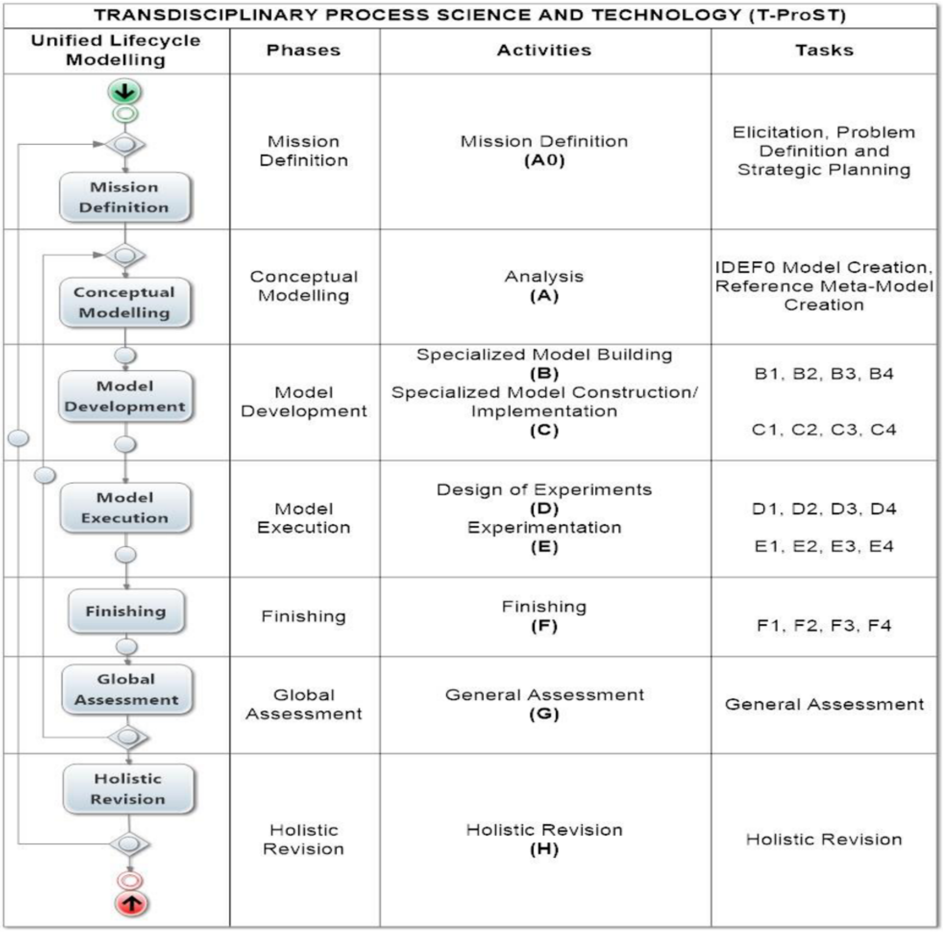

Figure 1. Transdisciplinary Process Science and Technology.

The Implementation Method or Unified Modeling of the System´s Lifecycle Process is created by the aggregation of the different worldviews used by the individual disciplines that are part of T-ProST. These disciplines are jointly applied making use of a reference model as a common basis for the uniformisation of the system´s description, representative of its essential structural and dynamical features. The implementation method comprehends the transformation of the reference model into the specialised models, their implementation, execution, analysis and assessment, initially as units, and later on as aggregate, yielding a complete multidimensional analysis of the system, based on a holistic view that encompasses all individual disciplines applied.

The mission Definition phase consists in the system or problem definition and the identification of the study´s objectives, which is performed in one activity divided into three tasks, denominated Elicitation, Problem Definition and Strategic Planning, for generality purposes.

The second phase is the Conceptual Modeling Phase, to build the hierarchical reference process meta-model in ULMD format, describing the operational processes, corresponding to the real transformations occurring in the system. This makes it easier for the different kinds of users and modelers to understand the system´s behavior, and later on to translate this model logic into their specific type of notations, in order to accomplish the specialised model building and construction phases.

The remaining phases are those shown in Figure 1 with their respective denomination and more detailed definition given by the decomposition of its respective macro-process into its components, consisting of composed or single activities, the last ones named tasks.

The four numbered types of Tasks B, C, D, E and F are those related with the four component disciplines of T-ProST (SE, PM, BPM, and SIM). They are treated separately during the phases of Model Development, Execution and Finishing (specialised modeling, execution and evaluation), and their results are integrated in the Global Assessment Phase, to yield a thorough assessment of the multifaceted model created making use of the transdisciplinary reference model.

3. Problem Definition

The Systems Engineering Body of Knowledge (SEBoK) [3] defines that the complete Systems Engineering´s Lifecycle (SE´s Lifecycle) comprises 4 (four) macro-processes, namely (Conceptual) Design Phase, Development Phase, Operation and Disposal. The problem domain of interest in this work is the design phase of the SE´s Lifecycle.

Figure 2 shows the SE´s Lifecycle design phase main processes, Conceps Definition and Systems Definition, and their decomposition, their sequencing and the feedbacks between these processes, obtained from SEBoK [3], with the addition of the processes Feasibility Analysis and Planning, in order to adequate it to project management and space sytems engineering standards.

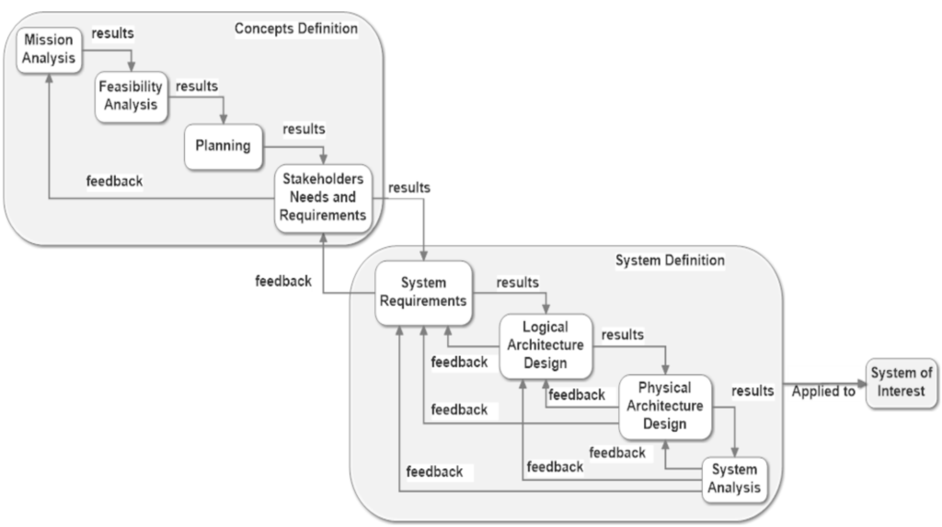

Figure 2. SEBoK [3] SE´s design phase processes, modified by the authors.

Any enterprise that has (Model Based) Systems Engineering (MBSE) as the main driver of its production processes may well make use of the concepts and definitions given in SEBoK to describe their product´s design phase according this structure.

During model execution several successive iterations and/or feedbacks are performed, until the final result is achieved, that is, the complete definition and specification of the System of Interest (SoI) is reached.

4. Conceptual Modeling

The Conceptual Modeling procedure consists in the formal description of the model through the realisation of two activities, namely The IDEF0 Model creation and the Reference Meta-Model Creation.

4.1. The IDEF0 Model Creation

Integrated computer aided manufacturing DEFinition for function modeling (IDEF0) [14] is a method designed to model the decisions, actions, and activities of an organisation or system. Effective IDEF0 models help to organise the analysis of a system and to promote good communication between the analyst and the customer.

IDEF0 models are often created as one of the first tasks of a system´s development effort. As a communication tool, IDEF0 enhances domain expert involvement and consensus decision-making through simplified graphical devices. As an analysis tool, IDEF0 assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong.

Each activity or function in the IDEF0 model may be decomposed in several layers or levels. The subsequent levels follow the same conventions as the previous ones, therefore a complete IDEF0 model is a hierarchical representation of the component processes described by their internal decomposition in activities or functions in whatever number of levels necessary to reach the desired level of granularity for a complete and detailed model description.

In the creation of the IDEF0 model one makes the hierarchical decomposition of lifecycle descriptive macroprocesses without the concern of the processes sequencing. The objective of the creation of the IDEF0 model is to identify the hierarchical processes themselves and their parameters of interest such as: inputs, outputs, resources or mechanisms used in their execution. The inputs and outputs may represent objects (raw materials or finished products, respectively) and the controls are usually associated with the standards and rules to which the processes are submitted.

4.2. The Reference Meta-Model Creation

The second task of the Conceptual Modeling Phase is the creation of the Reference Meta-Model, a process model based on the descriptive model and the addition of the sequence of execution or workflow of processes. The workflow for process execution is added at this stage of the unified model development lifecycle, making use of the ULMD notation

The generic reference model of the systems lifecycle process describes the complete process map with their time sequencing, the main actors or agents and their respective process lifecycle, separated in pools and lanes for which these actors or agents are responsible, the routing mechanisms and the flow of control for process execution, the diverse types of feedback loops, to perform some kind of rework or revision of products and objects that should have been previously accomplished.

The ULMD reference meta-model of the SE´s design phase is shown in Figure 3. The complete reference meta-model comprises: hierarchically displayed component processes; their main actors or agents designated as entities; their respective individual process lifecycles with their time sequencing; the complete description of the inputs and outputs (objects and messages consumed or generated by the processes); the control rules and norms used for the transformations; the human and material resources or mechanisms used by the processes; the interactions and connections links displayed inside the lanes or crossing over their borders. All of that is used as a baseline model to evolve to the next phase of model representation, known as the Specialised Models Development.

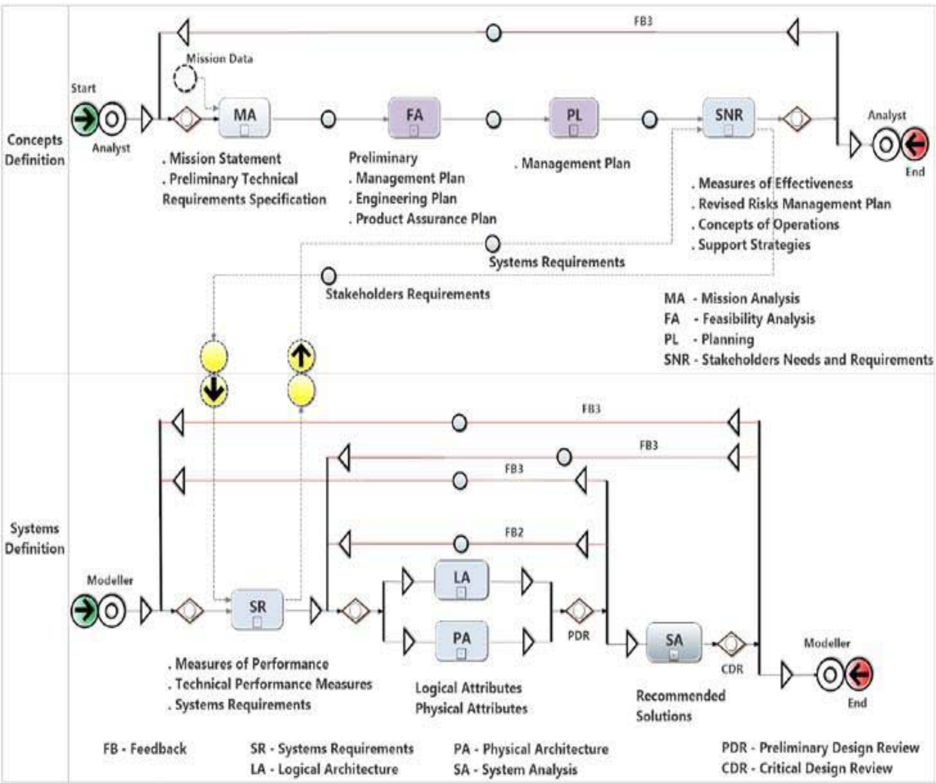

Figure 3. SE design phase – concepts definition and system definition – in ULMD.

4.3. Specialised Model Building

The specialised models are created gradually in the form of layers, the most internal one being the SE model, representing the systems engineering activities previously depicted in the generic reference model, equivalent to the core processes or real time transformation activities carried out for product development along its lifecycle, from its initial conception to its final stage.

The SE model expands the reference model and it represents the most complete description of the way the system is developed, acting as a configuration control system. This type of model is a descriptive model, that is, it is not intended to be executed as a process, it is intended to document the evolution of the system with all important information along the entire product development lifecycle, similar to a "recipe" on "how to produce the system", under an engineering point of view.

The PM model extends the SE model with additional PM processes, that is, it encompasses the activities needed for PM throughout the entire product development lifecycle. The PM model creation is considered as the application of PM techniques using a process-oriented view [5] supported by software tools.

The BPM model on its turn is built on the top of the PM model and extends it any additional processes required by the organisation for the complete management of its business processes, for example, with the ones related to the coordination of a portfolio of projects.

This gradual modeling and implementation procedure proceeds until the outermost layer is built, the SIM model, which encompasses all internal layers, made by the SE model with its core product development processes, the PM model with the additional PM processes and, finally, the BPM model, with the complementary business management processes carried out by the organisation during the complete product development lifecycle.

Any of the intermediary single layers can be treated separately and used for analysis purposes, in the traditional way their studies are performed. Simulation as a tool can also be used in association with any of the individual layers across the whole modeling procedure. The denomination of SIM model, however, is reserved for the fourth layer with the additional features necessary to conduct a complete simulation study of the SoI.

5. Implementation of Generic PLM Supporting Environments using T-PROST

PLM means Product Lifecycle Management, and its value is increasing, especially for manufacturing, high technology, and service industries. In fact, today PLM is widely recognised as a business necessity for companies to become more innovative in order to meet current challenges such as product customisation and traceability, growing competition, shorter product development and delivery times, globalisation, tighter regulations, and legislation.

The application of existing software tools originated from each of the individual study areas mentioned and the analysis of their integrated results in T-PROST can contribute to create a type of generic PLM modeling methodology and to build a general supporting environment, capable of performing systems engineering and management process modeling and analysis in a general context, and to significantly improve to the execution and management of the complete PM lifecycle activities.

The use of T-PROST for the implementation of a prototype of a generic PLM supporting environment has been the subject of a pilot project, which is explained in more details in a separate article submitted to TE 2016 [15].

These generic PLM can be used as an alternative to the use of complex, expensive and difficult to configure proprietary systems existing on the market. Their main potential users are designated transdisciplinary process-oriented Small and Medium Enterprises (T-SME organisations), who conduct highly advanced technological systems project developments, yet characterised by low to mid-level complexity technical processes, short concurrent engineering lifecycles, and severe budgetary constraints.

6. T-ProST´s Benefits and Limitations

T-ProST presents an interesting alternative way to improve the solution of problems involving complex business processes. T-PROSTS´s innovative holistic view addresses both the restructuring of the knowledge content (descriptive view) and the creation of a general systematic modeling procedure (unified process view), making use of reference models to base the individual or combined use of the diverse modeling techniques to create transdisciplinary multifaceted models.

The disciplines SE, PM, BPM and SIM incorporated in T-PROST are long established disciplines, with mature methodologies and supporting tools and large communities of users, therefore they encompass a wide range of methods and techniques used to deal with discreve event process problems in general. Their different types of worldviews, techniques and supporting tools are well known to their respective communities of users, although there is a lack of communication between them.

The T-PROST´s holistic view strives to unify the concepts, methods and tools from these diverse techniques and to jointly apply them in an easy and consistent way, integrating the work of multidisciplinary teams, reaching the same complementary benefits from their individual use and, at the same time, avoiding any overheads, inconsistencies and duplications related with their joint application.

The proposed methodology can be applied to a large problem class dealing with complex discrete event process systems in general. This holistic approach could consolidate all the scattered knowledge on complex process under a single umbrella, capable of covering the entire problem domain and covering the complete process model lifecycle.

There is an expected overhead in this attempt to apply a transdisciplinary approach based on existing autonomous tools, represented by the expensive procedure in regard to maintaining model consistency and compatibility across the whole model development lifecycle.

The overhead resulting from the application of a unified approach right from the start of the modeling process is seen rather as an anticipation of future problems, which might remain unsolved if the traditional way, based on independent application of the techniques and the gathering and interpretation of their results to build a global solution thereafter, is applied.

This drawback can be reduced in future studies of this kind by the development of supporting environments made of an assembly of interoperable tools [15] and the use of formal verification procedures and of software mechanisms to improve process model consistency and compatibility.

7. Conclusions

The methodology has been applied in a real scenario of a small satellite project development conducted by the students of the postgraduate Course on Systems Engineering and Management (CSE- 331/ETE/INPE).

The application of the T-PROST Framework for small satellites project development is documented in [15], and it was performed as a class project, making use of Simprocess as its main software component, used as GUI for the reference model building, and some Commercial Off-The-Shelf (COTS) systems with open license or low cost academic versions as the additional tools for specialised model building.

The full benefits of T-PROST shall be achieved in the long run by the design and implementation of hybrid PLM supporting environments capable to deal simultaneously with all the issues involved in the individual study areas. Different complete generic PLM supporting environments of this type can be built to allow the modeling and analysis of a production process as the application of basic SE, PM, BPM and SIM tools, in substitution of complex PLM systems [15], which are costly and difficult to customize.

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Adaptive Control Applied to the Performance Management Function of Organizations

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Abstract: The adaptive systems theory is commonly applied to the control of complex technical systems such as autonomous vehicles. In such cases, the environment of the system is in constant change and the system needs to transparently respond to these changes in order to timely fulfill its objectives. Organizations, considered socio-technical systems, also operate in a dynamic environment. Organizational theory, however, usually regards change as a process and not as an inherent characteristic of the system, addressing the need for change instead of transparently embedding it into system design. This work addresses this issue in the performance management function of an organization by proposing an architecture for information systems based on the adaptive systems theory that intrinsically treats change. In particular, this is accomplished in the metrics and assessment procedures of the performance management function. Metrics and procedures, in this sense, may change over time and are not the result of a deliberate change process, but of the way that the performance management function is implemented through this architecture using an enterprise engineering approach. A proposal for the application of this architecture is presented in the service sector, more specifically related to the Brazilian public education, and the extension of this architecture to encompass other types of organizations and functions is discussed.

Keywords: adaptive systems, performance management, performance measurement systems, enterprise engineering, co-production.

Introduction

Any system changes with time. Mechanical systems wear out, social systems (organizations) suffer drastic changes as new generations replace previous ones, and

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production systems must be adjusted to market needs. In all these cases, the need for adaptation is inherent to the process. Such adaptation can generate new kinds of performance, which can be either good or bad.

To evaluate the performance of an organization it is possible to use performance assessment frameworks such as the Balanced Scorecard methodology (BSC), which is broadly applied, but is too generic, and whose focus is not on people. In this article our focus is on people (workers) and how we can help them achieve the best performance at work. The main idea is: if all workers are doing their tasks at high levels of quality, the institution is doing well.

According to Neely *et al.* [1], one of the key questions that have to be considered during the development of a balanced scorecard (BSC), and thus in the development of any such performance assessment framework, is how specific measures of performance should be designed. The danger is that if a simple formula is created with no criteria, individuals who participate in this process might be encouraged to pursue this goal inappropriately. Proper design should consider not only a robust formula but also the source of all data.

According to Bourne *et al.* [2], performance measurement systems require developing and reviewing at a number of different levels as the situation changes. For example:

- the performance measurement system should include an effective mechanism for reviewing and revising targets and standards (Ghalayini and Noble, 1996, *apud* Bourne *et al.* [2]);
- the performance measurement system should include a process for developing individual measures as performance and circumstances change (Maskell, 1989; Dixonetal., 1990; McMann and Nanni, 1994, *apud* Bourne *et al.* [2]);
- the performance measurement system should include a process for periodically reviewing and revising the complete set of measures in use. This should be done to coincide with changes in either the competitive environment or strategic direction, (Wisner and Fawcett, 1991; Dixonet *et al.*, 1990; Lingle and Schiemann, 1996, *apud Bourne* et al. [2]; and
- the performance measurement system should be used to challenge the strategic assumptions.

All of these can be achieved by an adaptive loop for control and automation of the indicators. When there is a group with a systematic poll, best practices can be selected to be used in the services annually. All of these ideas aim at increasing the quality of service.

A major problem in assessing the quality of the service is the inappropriateness of the indicators used. People do not accept assessments when they consider them out of scope, out of focus or inconsistent with the reality of everyday life. To minimize this problem, it is very important to use 360º poll (as a 360º feedback) to find the most important evaluation criteria and to set priorities.

The engineering of control systems is a complex task because it involves mathematical models to represent mechanical, electrical, chemical, biological and sociological systems. When complex tools are used to analyze humans and their work, a socio-technical system is being determined. A socio-technical system is a social system operating on a technical base, and it is one of the most common types of systems these days.

The closest one can get to a good evaluation system for public services is one which uses items that are added to adaptive control theory as proposed by Bourne *et al.* [2], such as the following four items:

- the one who is evaluated should contribute to the evaluation criteria. In this case they will indicate their practical knowledge of the activity;
- the assessor contributes to the quality of the service indicators for the area (what is good for him/her), and also makes a direct evaluation of the service provider, giving feedback and helping with practice improvements;
- both the evaluation system criteria and feedback need to be adapted to the environment and accept more than one area of evaluation, because various working positions have more than one type of activity; and
- feedback must be at the same level of complexity (level of understanding) for all users (evaluators and evaluated) and feedback cannot be given in just one or two instances; it needs to be constant and statistically accurate, and create a database for comparisons between past and present.

To try to design a system with the qualities listed above, an approach with a good control system technique will be used. Our focus is on adaptive control because dynamic systems (the processes) often change over time. Adaptive control is a control methodology that is capable of dealing with uncertain systems to ensure the desired control performance [3]. There are many approaches and definitions of adaptive control. According to the the Webster dictionary, adaptation means: (i) adjustment to environmental conditions; and (ii) alteration or change in form or structure to better fit the environment.

According to Aström and Wittenmark [4], a controller with adaptive characteristics has adjustable parameters as well as a mechanism for adjusting such parameters. An adaptive controller has useful properties that can be profitably used to design control systems with improved performance and functionality. This proposal leads to organizational innovation by designing or changing the form of an organization's structure (organizing to work) in order to gain speed, agility, flexibility and capillarity in achieving its goals (e.g. organization chart, hierarchy chart, downsizing, etc.).

For a person who is not a student of control systems, it is important to clarify that adaptive control systems have been studied for a long time and have solid applications, such as: autopilots for missiles, ships and aircraft; motion control; machine tools; industrial robots; distillation columns; chemical reactors; and pH, heating, and ventilation control. There are also applications in the biomedical area because of the level of uncertainty and its consequences [4].

According to Tao [3], as a popular control methodology of increasing interest for applications in engineering and science fields, adaptive control has its unique abilities to accommodate a system's parametric, structural and environmental uncertainties caused by payload variations, system aging, component failures, and external disturbances.

There is a great number of systems, techniques and proposals in literature to systematize or improve quality, but they are merely theoretical and not professionally practical, and these actions solve just a small number of cases, such as a first order equation. We need to improve the system with a better algorithm to overcome such limitations. If we use a second order equation (which is more complex than a first order one), we can obviously include many more items, but this has its price due to the expanded complexity.

Figure 1 below shows a block diagram of a classical adaptive control system. For the assessment of services, this work proposes the use of a self-tuning system to prioritize the main "best practices" (indicators, variables, evaluation criteria, etc.).

According to Aström and Wittenmark [4], an adaptive controller is defined as a controller with adjustable parameters and a mechanism for adjusting these parameters. The construction of an adaptive controller thus contains the following steps:

- characterize the desired behavior of the closed-loop system;
- determine a suitable control law with adjustable parameters;
- find a mechanism for adjusting the parameters; and
- implement the control law (this item is critical for a good performance).

The items above can be applied to the service area when we use statistics as an interface between humans (who execute or receive the service), and a control loop for processing and optimizing the variables to be measured (indicators, best practices, questions, etc.).

Using Tao's indications as a basis [3], there is a vast amount of accomplishments in adaptive control techniques, such as multivariable adaptive control for MIMO (Multiple-Inputs and Multiple-Outputs) systems, which is an open area for research of both theoretical and practical importance, especially as new problems arise from applications such as spacecraft flight control, sensor networks, cyber physical systems, multi-agent systems and smart grids, and other complex systems.

According to Aström and Wittenmark [4], a simple characteristic feature of direct adaptive algorithms is that the closed-loop behavior can converge to the desired behavior even if the parameters do not converge.

Some characteristics of adaptive control are:

- real-time applications;
- applicability in non-linear systems and time-varying systems;
- accuracy in system modeling is not necessary;
- adaptation in adverse conditions ("it learns").

Students of control techniques must be careful not to mix control theory techniques. An adaptive control has a fixed structure in which you can change parameters, and this range of parameters for variation is known. Robust control will make systems work more slowly but you do not need to know the limits of the parameters. Intelligent control has the possibility of changing the structure of such control, but this is not the focus of this research. To a non-control engineer it may seem that all these items are the same, but they are not. [3] reports that there are other important adaptive control topics such as: stochastic adaptive control, adaptive predictive control, adaptive control of hybrid systems, adaptive learning control, adaptive variable structure control, adaptive systems with delays, and so on, which are not covered in this paper.

Chapter 1 is about how to deal directly with the subject, using mathematics and engineering to calculate and systematize this framework of information. Chapter 2 shows one example of an adaptive system specially designed for assessment on professional learning and higher education in classrooms. Chapter 3 is the conclusion.

1. Development

Here is a narrow definition of adaptive control: an adaptive controller is a fixed-structure controller with adjustable parameters and an algorithm for automatically adjusting those parameters. An adaptive controller is one way of dealing with parametric uncertainty. Adaptive control theory essentially deals with finding parameter adjustment algorithms that guarantee global stability and convergence. In this article our "controllers" are the people who aim at doing the best practices in their workplace.

In control engineering, it is a system of control that can automatically define the parameter for the control (good but not optimal) using an algorithm for searching this parameter, which is called a self-tuning controller. According to Mikle and Fikar [5], the self-tuning controller structure consists of two loops. The inner loop contains a linear feedback controller with time-varying parameters. The outer loop contains an identification algorithm and a box that adjusts the controller parameters based on the identification results. This continuous loop for identification creates an adaptive controller (advisor) which can adjust the behavior of the process in real time to get a good performance.

When you have a great number of individuals involved in service delivery, statistically speaking, you will have a large standard deviation (SD) unless you have an orientation and learning system, because each person will perform the work in accordance with his/her religion or philosophy of life, sexual orientation, nationality or culture, area and level of education, etc. Figure 1 below shows how to adapt a classical adaptive control system into a complete (and complex) system of evaluation with the definition of indicators in real time.

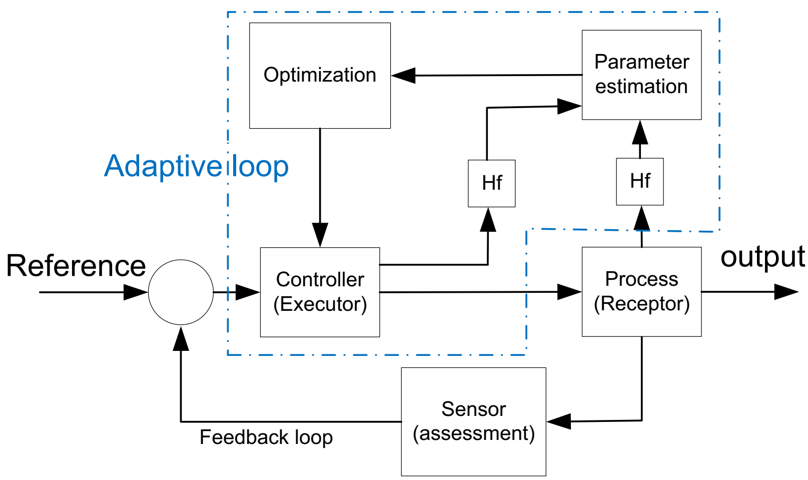

Figure 1. Adaptive system for the assessment of service quality with adaptation of behavior.

The main items to consider in Figure 1 are:

Reference: the level of necessary user responsibilities, for example: students of electronics need to know much more about electricity than students of mechanics or administration.

Controller/executor: these are the professionals who will execute the service, for example: doctors, teachers, police officers, mayors, drivers, etc.; these people need to know the main "best practices" and the level of effort to achieve the necessary criteria.

Hf: it is really necessary to have a set of statistical filters in order not to accept malicious opinion or opinions related to a "perfect world", for example: we should evaluate only those (all) in the circle of service; pseudo researchers who speak without truly knowing the practices should be immediately removed from the references, otherwise they can generate noise and disturbances within the system (this phrase is not malicious, these are technical terms of system control area).

Sensor/assessment: when working with people, it is necessary to use forms to get answers on the services provided; this information must be used for guidance and must not be ambiguous; this sensor is only for the evaluation of the service; it is part of the internal control loop and is the lifeblood of any controlled system; in this approach, the loop is used as an assessment of the service quality, without which there really would be no control in the system;

Process/receptor: the process is the reason why the service is provided, for example: teachers need to teach, medical staff need to treat patients, managers need to manage, engineers need to create, design or optimize, etc.;

Parameter estimation: this box indicates the algorithm, function or technique for finding the correct set of indicators, variables or assessment criteria for the next sample (feedback); below we will show a control law for selecting the best practices for services;

Optimization: this box determines the application of parameter estimation on the controller; it is necessary to present best practices formatted with the possibility of external evaluation and internal understanding by the users of the system, for example: an international presentation for accreditation of educational services.

To find the correct parameter for the evaluation of services with a focus on execution, we need a methodology to see what the receptor wants, what the executor thinks is correct and what all other equivalent service groups are doing. It gives us a triangulation in order to prevent the use of a biased or malicious parameter, which is an important concern when working with human data. Mathematically, it can be represented by one intersection between these three groups. If we have groups A, B and C, the best parameter (P) for work can be found with $P = A \cap B \cap C$.

To give us stability when controlling a system, we need to understand the dynamics of this system as a mechanical, electrical, chemical and social system. When we have inertia, our system is slow. When we have few points of relationship, our system is simple to understand and control (as a first order system used as a simple mathematical model of system, for example: thermal heating). With one orientation for optimization it is possible to have a fast change of parameters for the assessment of services, but it needs to be controlled precisely, because fast and continuous changes can cause instability in the execution of the service (in engineering, it is an instability in high-frequency responses). Think of a group of parameters (one set parameters) that changes annually, for those who are focused on doing a good job this change will make a person feel lost and he/she will not agree with the parameters used. In this case, we need to put inertia on parameters review. Information systems can be very fast, but we need to respect human inertia.

According to [4], when the process parameters do not change (they are constant), the estimation routines are usually such that the uncertainties decrease rapidly after the estimation is started, but the uncertainties can be numerous at the start or if the parameters are changing. In such cases, it may be important to let the control law be a function of the parameter estimates as well as of the uncertainties of the estimates. The control law approach used in this work is shown below as an algorithm for searching the assessment indicators (variables):

1. Start processing;
2. Load poll - group A; // Example: Students
3. Load poll - group B; // Example: Teachers of University 1
4. Load poll - group C; // Example: teacher of all others universities equal B
5. $\theta_n(t) = MAX_n(A \cap B \cap C)$;
6. Use the new set of indicators $\theta_n(t)$ in the assessment (new rank);
7. End processing.

In the algorithm above, *n* is the number of indicators (variables, best practices, etc.) that will be used in the evaluation or comparison. This number is not fixed and can change according to the area, maturity and number of people involved in this process of improvement. For example, in a group of 250 indicators it is impossible for anyone to work with all of them at the same time, so only a smaller set of the most important for all the groups involved is used (for example, $n=10$).

Any system has losses. Human work has the normal characteristic of being stable at low levels of productivity, and with the passing of time quality decreases. To deal with this problem, humans have created tools. One example of a tool for improving the quality of public services is using a list of common actions to be followed. It is important for a real-time system with support to improve work, but if the quality of services changes, we need to systematically improve those changes. The primary reason for introducing adaptive control was to obtain controllers (and executions) that could adapt to changes in process dynamics and disturbance characteristics [4]. It has been found that adaptive techniques can also be used to provide automatic tuning of controllers and the fundamental property is that feedback systems are intrinsically insensitive to modeling errors and disturbances.

When you have a system to measure quality, although it may contain errors, it is possible to analyze the index of absolute error (IAE). In control engineering the integral of absolute error is used [6], which is an instrument for establishing performance criteria when a new controller is designed. In this work, the use of IAE to achieve a good level of service quality can be used. All the steps of the algorithms are important, but the heart of adaptive systems resides in steps five and six.

To demonstrate everything that has been said, the next chapter describes an example of how the steps have been applied on the assessment and improvement of public education service quality.

2. Practical example

According to Machado *et al.* [7], the development of evaluative research also indicates the importance of evaluation as a way of judging processes and actions, but it brings the apprehension that evaluation is production of knowledge.

The example in this work example uses a list of items to be valued (measured) in the classroom by students. The exact indicators will not be studied, because another article would be necessary to define these indicators. All indicators will be numerated as Qx, for example: Q1, Q2, Q3, Q4, etc.

Using Figure 1 and the control law algorithm presented in the previous section, it can be demonstrated the optimization and adaptation by teachers and students in the service of teaching and learning. These two groups have different opinions about the questions and they need to be respected, and only the intersections of these two groups can be used in the next sample for assessment. If just one group lists the evaluation criteria, this system will not work for its real purpose, but it will work for facilitating one subgroup. For example, if just students list the criteria, they can select "Teachers must award a pass score to all the students of the course", and this is obviously wrong, after all, no one would want to use the services of a doctor who has obtained his title without due merit.

In Table 1, an example of the proposed adaptive system is shown. In this example, the best practices are called Qx and they have a level of acceptance or preference, and by using the algorithm of adaptation the most important indicators found in the intersection of the groups in the circle of service are raised, while those which are not so important are decreased. With this framework of information based on systems control, priorities in the execution of the service can be selected and quality can probably be improved.

Table 1 shows one example (simulation) of how to calculate the questions (best practices, tasks) per year. Figure 2 below shows an example of this methodology with data collected from 2009 to 2014. It shows the indicators (variables) increasing and decreasing by the necessity poll with the groups involved (students and teachers).

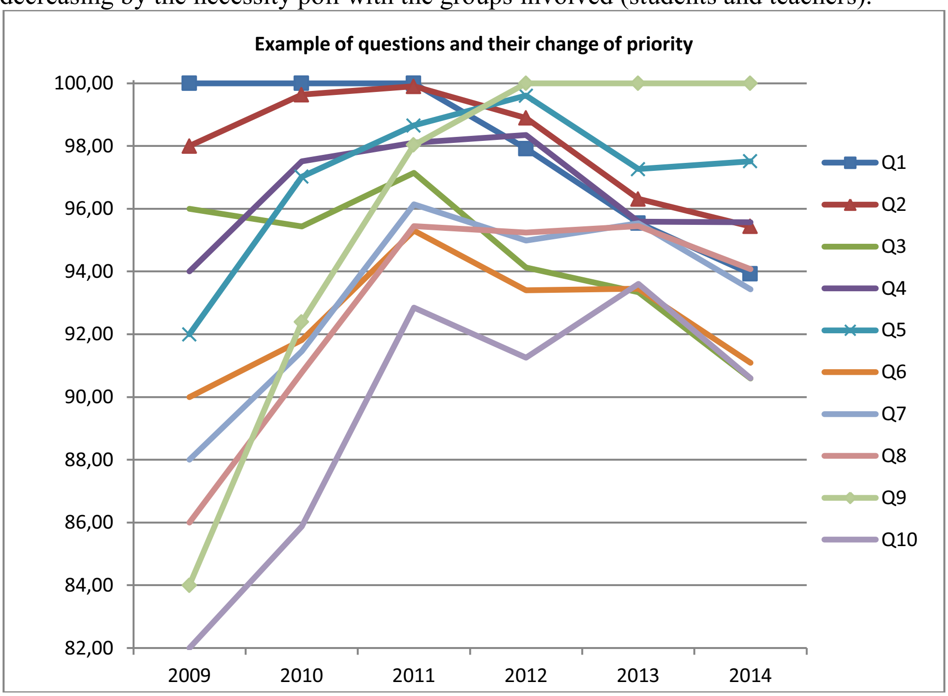

Figure 2. Example of adaptive system for analyzing quality in education with change of questions to define priority in the assessment – real-time optimization. Qx are the possible questions (tasks) in the questionnaire.

As can be demonstrated graphically, sometimes the administration of one institution of education may select the wrong set of questions for evaluation. But with a transparent system which uses scientific theories such as system control, systems engineering and statistics for interface, it is possible to generate a good tool for guiding work.

Table 1. Example of law to adapt the indicators for researching "best practices" for the classroom.

2009		2010		2011		2012		2013		2014	
Q1	100,00	100,00	Q1	100,00	Q1	100,00	Q9	100,00	Q9	100,00	Q9
Q2	98,00	99,63	Q2	99,91	Q2	99,61	Q5	97,26	Q5	97,52	Q5
Q3	96,00	97,51	Q4	98,65	Q5	98,90	Q2	96,31	Q2	95,57	Q4
Q4	94,00	97,02	Q5	98,10	Q4	98,35	Q4	95,59	Q4	95,44	Q2
Q5	92,00	95,44	Q3	98,03	Q9	97,92	Q1	95,55	Q1	94,08	Q8
Q6	90,00	92,39	Q9	97,15	Q3	95,24	Q8	95,54	Q7	93,93	Q1
Q7	88,00	91,81	Q6	96,15	Q7	94,98	Q7	95,45	Q8	93,43	Q7
Q8	86,00	91,46	Q7	95,44	Q8	94,13	Q3	93,61	Q10	91,09	Q6
Q9	84,00	90,79	Q8	95,31	Q6	93,40	Q6	93,46	Q6	90,60	Q10
Q10	82,00	85,88	Q10	92,85	Q10	91,26	Q10	93,34	Q3	90,59	Q3
Q11	80,00	81,66	Q13	90,32	Q13	89,46	Q13	92,76	Q13	89,88	Q13
Q12	78,00	79,77	Q11	88,42	Q11	87,08	Q14	92,02	Q17	88,01	Q17
Q13	76,00	79,39	Q14	88,10	Q14	86,09	Q17	91,64	Q20	87,52	Q14
Q14	74,00	78,72	Q12	87,46	Q15	85,50	Q15	90,54	Q15	87,42	Q20
Q15	72,00	76,94	Q15	87,30	Q12	84,35	Q20	90,54	Q14	86,36	Q15
Q16	70,00	74,95	Q17	87,23	Q17	83,42	Q11	89,26	Q19	83,18	Q19
Q17	68,00	73,10	Q16	85,69	Q16	83,02	Q12	88,96	Q16	82,76	Q16
Q18	66,00	70,94	Q18	85,03	Q20	81,74	Q16	88,28	Q11	82,54	Q18
Q19	64,00	70,58	Q20	83,98	Q19	80,93	Q18	87,71	Q18	82,29	Q11
Q20	62,00	69,29	Q19	83,52	Q18	80,90	Q19	87,60	Q12	82,17	Q12

In Figure 2, it is possible to see that task (best practice) Q9 rises and becomes the most important item to be used in evaluation, whereas task Q1, initially defined as the most important, decreases to the sixteenth position, and task Q3, initially set as the third most important, changes to the ninth position, closer to be excluded from the set of variables ranked. Q5 changed the fifth position for second.

To bring stability to the system, we need to use the mathematics intersection, because then only common "best practices" will be used. Also, malicious or corrupt questions and indicators will be removed by that mathematical intersection because, by definition, corrupt systems are those that cater only to a small group, opposing the whole.

Evaluation systems and indicators should be well designed and take into account "outliers". Unfortunately, malicious people may want to get the advantages of a high score without proper effort. With the proposed architecture, a small group (corrupt) will rarely be able to take advantage since the selection criteria is basically made in 360º and the assessment is ongoing.

Based on the positive results of the simulation, the next step will be the construction of the online platform that will allow the selection of parameters and evaluation of users (candidates). It is expected to verify that the evaluation architecture is efficient, works for several different areas and in different organizations.

According to Figure 2, the final indicators scored in order of priority were achieved through annual interactions between the groups involved (in the example: teachers and students), so best practices have been found and can be used in daily life for new professionals as well like the old, have a correct orientation and achieve high levels of productivity in their institutions, thus improving the quality of service.

3. Conclusion

Control engineering can be a great tool for solving problems with wide scope and complexity. In this article, it was demonstrated how to use this powerful tool to answer two problems at the same time: how to define a framework to find the correct tasks (questions, best practices, variables) for assessing the quality of the service and how to use such framework to evaluate workers.

Analyzing adaptive systems is difficult because they are complicated; the theory is useful to show fundamental limitations and characteristics of the algorithms and to point out possible ways to improve them, from mechanical to organizational systems.

The presented algorithm with the adaptive control rules demonstrated by simulation that this methodology can be used to rank and find the best practices of each work activity, particularly in the provision of services. A database with polls will be created next in order for the improvement of the quality of service in public service to be done in the near future.

The information system is the bottom-up where each expert group defines its rules, or is distributed among the sectors/areas, and not a general direction indicates which are the indicators for evaluations. This model appears to be interesting for the evaluation of systems working with coproduction.

In future works, it will be demonstrated how to use the characteristics of controllers with moving average and adaptive self-tuning to rank scientific works. There is more than one methodology to measure this; in some specific cases there are methods used only in one country, for example the Qualis rank in Brazil.

In addition to a technical condition that prevents the use of malicious indicators, the intersection of systems creates transparency, which is a fundamental part of the open dialogue that is an integral value for transdisciplinarity.

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Introduction of a Goals and Characteristics Model for Implementing the Product Line Concepts: An Application in Civil Engineering

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Abstract. The introduction of new products is a critical aspect for the survival, growth, and rentability of enterprises. Mass customization has aided to decreasing the production costs and the time to reach the final consummator. But, the rapid change in technology and in social and individual expectative, as well as, the explosion of the concurrence demand new and efficient methods for products development. In order to assume these challenges, products lines approach looks for the reuse of common characteristics of products and the harnessing of the variability of other characteristics useful to satisfy exigencies of customers. The features model, widely used in the development of products lines, has limitations to treat the complexity of domains, to adopt standard guides to construction and segmentation of domain models. In our research, domain knowledge is organized in different ways, in order to represent tangible and intangible realities using mathematical, conceptual, and physical models. Traditional engineering, as mechanical, civil, materials, and hydraulic has important applications in automotive, and aerospace industry, and in the construction of ships, buildings, railways, roads, among others. There, it is easy to appreciate the common use of ideal, conceptual, and physical models in projects development. In civil engineering, for example, new structural elements, their conceptual representations, mathematical models, software systems for analysis and design, and physical models use concepts of a domain model, which depict common and variable characteristics of a products line. In this work, we model domain in terms of goals and characteristics, highlighting the reusable part of products and the variability. This domain model allows the application of products line concepts to the analysis, design and construction of structural elements in civil engineering. We apply proposed products lines models in the analysis and design of coupled structural walls.

Keywords. Products line, domain model, goals and characteristic model

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Introduction

Domain knowledge is an essential concept in the development of problem solutions. In software engineering, the methodologies for developing Information and knowledge systems consider the domain model in the earliest phase of the systems lifecycle [1] [2]. In software development and Requirements Engineering have been introduced widely applied domain concepts and models such as Domain Analysis. This one involves the identification, capture and organization of essential knowledge for systems developing. This approach introduced by Neighborn [3] was complemented -among others- by McCain [4], Prieto-Diaz [5], and Maiden [6]. Another fundamental contribution to the domain concept is the domain meta-model. Ramadour and Cauvet, in [7] propose a formal domain meta-model which considers object, activity, and goal as fundamental concepts. This domain characterization encloses the context knowledge as a part of the domain knowledge. Context knowledge is used for doing the choice of goal components, activity organization and object descriptions.

A short glimpse into the methodologies for systems development allows classify the domain models in two categories: information representation-based models and data processing-based models. In the first one, two sub-categories are recognized: Hierarchical Information Structures and Graphs of Information Structures. Hierarchical Information Structures include Domain Ontologies and Structures of Domain Services and Objects (SDSO). This structure has as head concepts system functionalities, which enclose the domain concepts and the relationships among them. We introduce in [8-16] the SDSO, as a simple way to obtain domain ontologies. Domain Ontologies are based in germinal works of Bunge [9], Gruber [10], and Borst [11], among others. Some contributions about domain ontologies in Civil Engineering appears in [12]

In the category of Hierarchical Information Structures appears the Features Model, a domain model proposed by the Software Engineering Institute of Carnegie Melon University, widely used in the Products Lines development.

Graphs of Information Structures contain Entity-Relationship Diagrams developed by Chen [13], classes graphs treated -among others- by Shlaer and Mellor [14], Booch [15]; and Frames created by Minsky [16].

Data processing Models correspond to classical approaches, which use the Data Flow Diagram (DFD) as the System Conceptual Model. First abstraction level of the DFD is named context model, where external agents interact with the system. Requirements elicitation is based on low abstraction levels of the DFD combining domain and context concepts. An agent is an object responsible for individual actions or interactions

Context and domain concepts are differentiated in [17]. Context is a space where agents, agents' goals, intentions, decisions, actions and interactions, their involved circumstances, means, methods, resources, and other related objects exist and give meaning and value to the knowledge influenced by this context.

The *domain*, in relation to knowledge and information systems, is the real or imaginary field on which the system and their related agents intervene. This is the field in which the knowledge associated to related product, services, and objects is managed by knowledge and information systems in order to support activities and conditions on this domain. Thus, *domain* is a real or imaginary activity field integrated by products, services, objects, and relationships among them, containing the knowledge on which agents from different contexts intervene aiming to satisfy specific objectives.

The Products Line approach for products development shares commonalities and incorporates optional domain features that determine different products, belonging to the same line. It is possible to configure and personalize thousands of products according to a set of restrictions. The Product Line Engineering potentiates the reuse of common and the use of optional features taking advantage of features variability. All features and their relationships belong to the domain model. Features Models aim at representing the domain of a Products Line. This concept is now widely used in software and manufacture industry [18-24].

The size and complexity of domain models, the mix of context and domain knowledge and the exigencies for rapid development of products claim for deeper analysis of domain characteristics, definition of new concepts for the fragmentation of domain models, and more support for the modular, and interactive products construction. In general, the existing Requirements Engineering methods are insufficient for the delimitation of concepts and their inclusion in the domain models. It misses consolidated approaches for the fragmentation of Features Models and the planning of modular construction of Products Lines. Besides, the extension of Products Line concepts in particular domains of other engineering fields is not an easy task. In this article, we take advantage of previously studied functionalities sets for heading the introduced Goals and Characteristics Model (GCM). Thus, systems analysts disposes of these sets of functionalities for elaborating or checking already elaborated domain models. The elaboration of GCM takes advantage of the functionalities-headed SDSO, which construction is easy and intuitive.

This work includes in the section 1, after of Introduction, the use of generic functionalities of an object in order to characterize and describe the life cycle of products lines. The proposal of a GCM, considering the reusability and variability is presented in section 2. The elaboration of a product line model for the design of structural element in civil constructions is considered in section 3. In section 4 the application of product lines approaches in coupled walls design is illustrated. Conclusion and future work is the subject of section 5.

1. General Functionalities for Heading a Goal Characteristics Model

The domain models centered in activities have the service concept, as root concept, and adopts goals (functionalities) as top concepts. A service is an intangible object, which cannot be owned, transported or stored. Products and services of a domain require the treatment of knowledge of this domain. The construction of products (tangible objects or containers) incorporates domain knowledge, while the development of services (intangible objects) manages domain knowledge [25]. We treat a service as a set processes managing domain knowledge, and use this service concept as root concept of a hierarchical representation of a domain, like the Structure SDSO, in [17], do it. The Goal and Characteristics Model, which will be in the next Section, has equally the service concept as the root. Specializations of this service are the functions expressed as goals that an object (solution) could accomplish. Two groups of generic categories of goals are exploited in this work: generic phases of a process, and generic phases of the lifecycle of a product or a service, Generic phases of a process encloses Preparation or Input, Transformation or Operation, Evaluation and Decision, and Result or Output. Generic phases of the lifecycle of a product or a service consider: Define. Analyse, Design, Construct, Test, Operate, Deliver, Maintain, and Remove. The goals associated to these generic phases head the GCM (domain model), for the development of a products or services [26].

The own functions of a product (tangible object or container) are supported on the objects and knowledge incorporated in its construction or contained in a tangible object. A product has physical nature or it is contained in a tangible mean. Indeed, a product may be physically possessed, transported or stored. For example, the elements to be incorporated in the construction of a vehicle belong to any function of the vehicle such as start, fuel injection, go ahead, speed change, turn, go back, brake, and turn off, among others. These functions involve concepts represented in the auto-motor domain. The own functions of a service (intangible objects) use objects and knowledge treated in the service realization. For example, rent a new car for a year is a service, which may be specialized in top functions such as: give information about vehicles and rent contracts, as well as, subscribe contract and assurance; configure vehicle; elaborate contract, manage contract, and manage post service. In turn, the function elaborate contract has the functions: deliver vehicle, use, repair, maintain, replace, and give back vehicle, as well as manage payment. The mentioned services are referred to the concepts related to the automotive domain.

Taking as headers of the GCM the phase categories of a process, the mentioned functions (goals) for the product and the service described in the last example, appears in Figure 1. Service may optionally link any phase category of a process, according to the Features Model. The explanation of this notation appears in next Section.

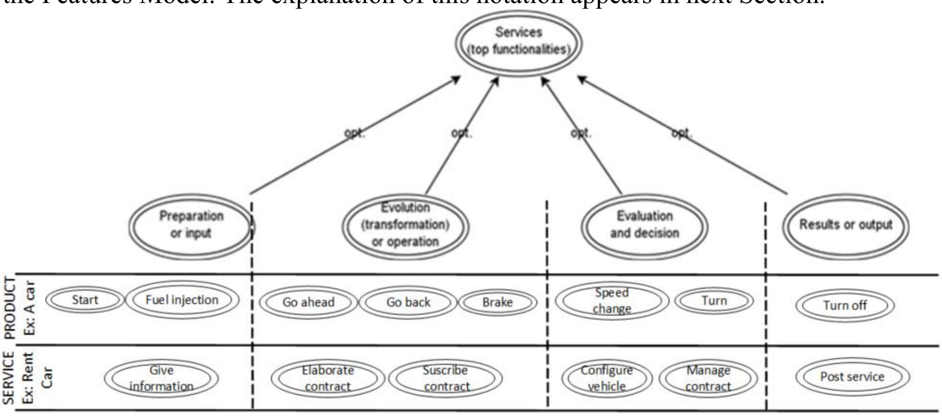


Figure 1. Headers as generic phases of a process applied to a product and a service.

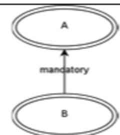
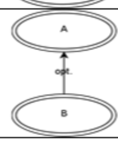
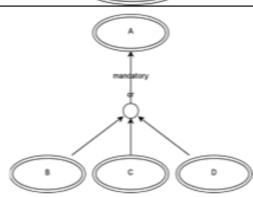
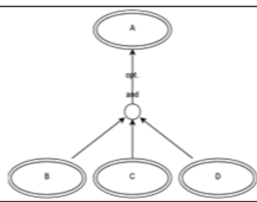
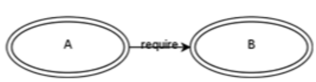
The interrelated concepts for accomplishing each one of these functionalities (goals) represent the domain knowledge.

Next Section introduce the proposed GCM, a domain model headed by goals corresponding to the generic functionalities sets treated in this Section.

2. Goals and Characteristics Models (GCM)

The development of Lines of Products or Services requires systematic delimitation, modulation, and construction of domain models, in order to support their segmentation. Physical and virtual segmentation helps for managing volume and complexity of domain models, as well as, reducing the management time, and the costs of treatment and storing. Segmentation allows optimizing the incremental guided interaction in recommendation systems. An intuitive and general solution may use any set of generic phase for the hierarchical representation of related domain concepts. Generic functionalities are instantiated for each particular product or services demanded by agents of any context. These instances determine branches connected with the root, each one for a particular service (goals). The name assigned to the root concept is a service related to the product. For example, *Vehicle Functioning Service* is the root, and start, fuel injection, go ahead, speed change, turn, go back, brake, and turn off are the top functions, which enclose the domain concepts. The desegregation of each top function reach the lowest concept that takes value and may be specified in programming languages in order to be processed by a machine. The relationships for completing the proposed GCM are those six of the Features Models, described below in Table 1. Column 1contains the names of the six relationships: Mandatory, Optional, Exclusive OR, OR, Require, and Exclude. Column 2 shows the graphical representation of the relationships, while column 3 contains the explanation of them.

Table 1. Relationships for Domain Model. Represented in the platform VariaMos.

Relationship	Graphical Representation	Explanation
Mandatory		If in a configuration of a product, the user selects the feature A, the features B will be selected compulsorily.
Optional		If in a configuration of a product, the user selects the feature A, the feature B could be or not selected in that configuration.
Exclusive OR		If in a configuration of a product, the user selects the feature A, only one of the children features (B, C, D) can be selected. It is enforced also via the aggregation properties of the relationships in the modeling tool.
OR		If in a configuration of a product, the user selects the feature A, one or more of the children features (B, C, D) can be selected. It has to be specified also via the aggregation properties of the relationships in the modeling tool.
Require		Selecting the feature A in a particular configuration, enforces selecting the feature B, but not vice versa. It is, selecting the feature B doesn't enforce selecting the feature A.
Exclude		Features A and B cannot be selected simultaneously in a given configuration of a product. Selecting the feature A doesn't allow selecting the feature B and vice versa.

In second level, top functionalities (goals), specializing the concept services, are linked to the root with mandatory or optional relationships. Generic top functionalities (goals) are instantiated according to the specific service.

Next Section contains the instantiation of generic phase categories for the early phases, from definition to design, in a Civil Engineering project related to buildings construction.

3. Elements of Products Lines Models for the Design of Building Structural Elements

The goal characteristics model, introduced in last Section, accepts different sets of generic functionalities (goals) for defining the top goals linked directly to the root concept, related to the same domain. Some sets of generic functionalities are: generic phases of a process, generic phases of the lifecycle of a product or a service, and generic functionalities related to an object. Process concept supports these approaches, which express functionalities (goals) identified in any mental and physical domain.

The top functionalities (goals) are referred to Lifecycle Phase Categories and Process Phase Categories in the bottom of Figure 2. The correspondence between both approaches aligns the Definition phase with Preparation or Input, the Analysis (Requirements Study) with Transformation or Operation, The Analysis (Logical Model) with Evaluation and Decision, and the Design Phase with Results or Output. This correspondence includes also the two high levels in Figure 2, under the root, which are expressions of the lifecycle of Civil Engineering Design projects. This lifecycle is characterized for methodological phases, expressed as: define areas and volumes, incorporate forces, moments, and deformations of structural elements of areas and volumes; assume forces, moments, and deformations of structural elements of areas and volumes; and determine materials and geometrics proprieties of structural elements of areas and volumes. Other characterization of the lifecycle of Civil Engineering Design projects is terms of the traditional models representing the life cycle phases: architectonic model, structural analysis model, structural analysis model for particular cases, and structural design model. The four categories of both characterizations are in correspondence between them and with the process phases categories and lifecycle phases categories. These correspondences allows expressive representation of domain models headed by mentioned functionalities in structural design of buildings, in Civil Engineering

In the same sense, in Figure 2, for the four generic phases of a process, their descriptions are linked mandatory to architectonic model, structural analysis model, selected structural analysis of specific models (with load cases), and structural design model, respectively. Additional semantic is introduced relating with mandatory relationships each one of the four precedent models with its corresponding product model. Thus, architectonic model is linked with general and detailed graphical representation of areas and volumes of a building, structural analysis model connects to logical model of structural elements of areas and volumes, selected structural analysis of specific models is linked with load cases models of structural elements of areas and volumes, and design model is related to concrete models of structural elements of areas and volumes of a building. From these four product models, the characteristics for developing each one are detailed and related using the six relationships of the adopted notation: mandatory, optional, exclusive OR, OR, require, and exclude. The variability of many concepts of these products models offers the possibility of generating a big sets of structural elements, a product line, including the common characteristics, for each type of elements, such as: foundations, slabs, roofs, walls, beams, and columns. In the same way, the variability of concepts leads to the development of sets of models, processes; analysis, design and construction methods, mathematical models, analysis and design software, buildings, and prefabricated elements.

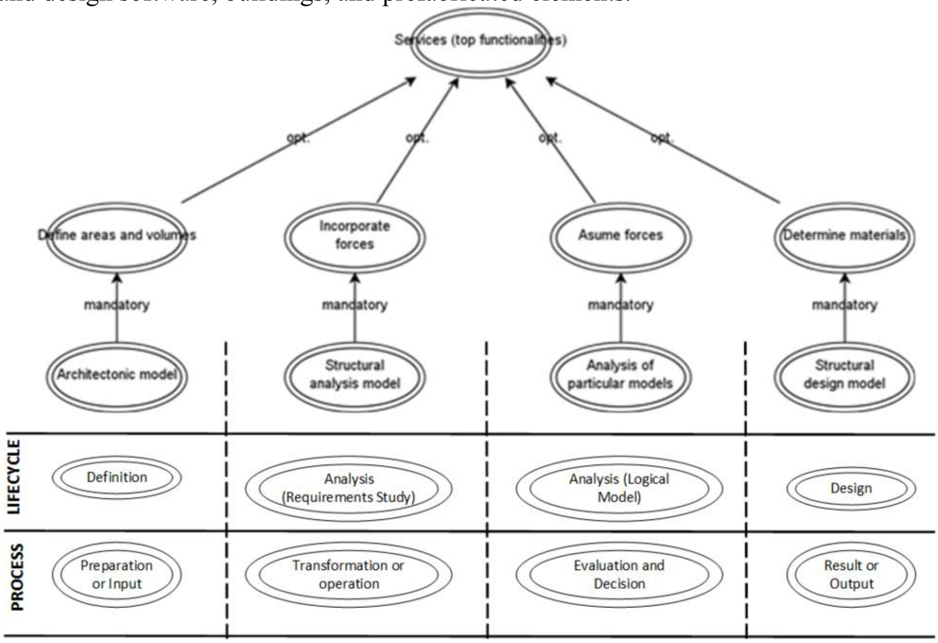


Figure 2. Headers for GCM.

4. Application of Products Lines Concepts in Coupled Walls Design

The first lifecycle phases of product, definition, analysis, and design, correspond to the generic phases of a process and to the generic functionalities of a product, as they were present in two last Sections. For highlighting the analysis of alternatives, evaluation, and decision, the central part of generic functionalities of an object, and the core phases of process, between Input and Output, are represented separately in our work. In [15] the lifecycle of a product is extended to the lifecycle of a Products Line. This extension allows us think in products lines of ideal, conceptual, and physical products, In this sense, in the domain of traditional engineering, in this case in Civil Engineering, Product Lines of process, methods, mathematical models, analysis and design software, graphical representations, structural elements, and completes reinforced and tensed concrete buildings are analyzed. The elaboration of these families of products continue joint with AREA Consultants Engineers, a Firma that looks for innovative products in Civil and Mechanical Engineering, with financial support of the National Learning Service (SENA), the official national training Institution in Colombia.

A products Line model for concrete reinforced and tensed building was elaborated, for the constructions of reinforced and tensed concrete building.

Several logic structural systems are considered: frames, dual systems, and coupled walls. In this work, the application case in coupled walls is introduced. Figure 3 depicts an extract of the GCM related to coupled walls, a logic structural system integrated by walls and beams.

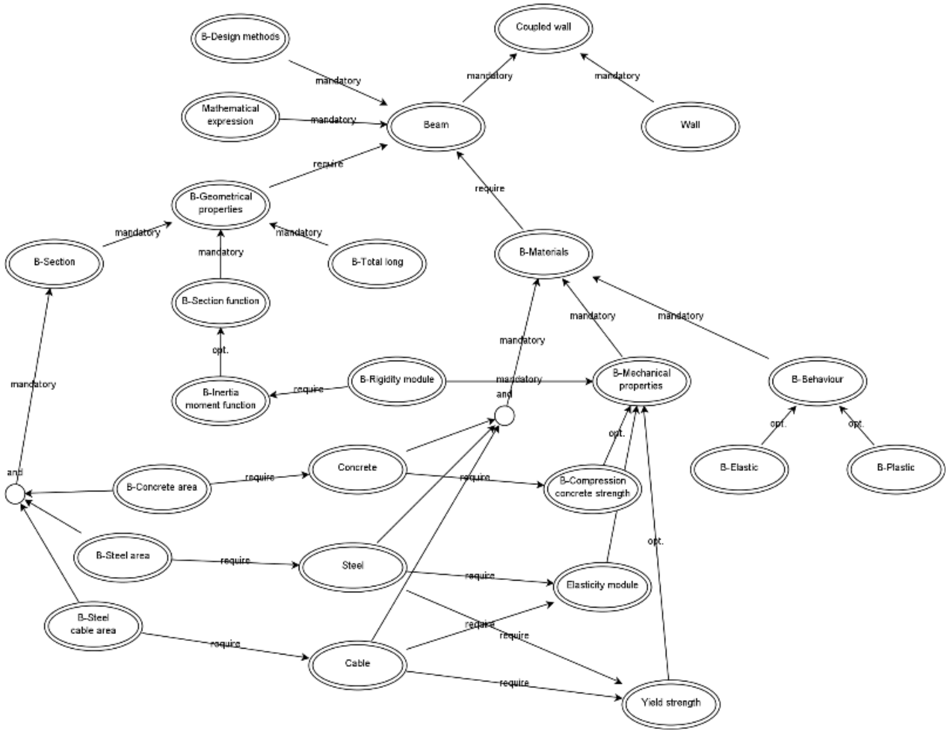


Figure 3. Extract of Design model for coupled walls.

For sake of space, only an extract of beam characteristics are drawn. The branch of walls contains the same elements with different name. Architectonic model, structural analysis, structural load cases, and structural design models constitute the domain model, integrated in a big goal and characteristics model, represented in the platform VariaMos. This one is a tool in construction, in order to support the development of products lines. The whole model does not suit here. In coupled walls systems, beams and walls are mandatory concepts of coupled wall systems. B-design method, B-mathematical expressions, B-geometrical proprieties, and B-materials are mandatory concepts related to B-beam. B-materials may have mandatory B-Mechanical proprieties, B-behaviors, and at least a material, among B-concrete, B-steel rod, and B-steel cable. Other materials may be included. These options constitute a variability point, which give place to different products. B-section and B-long are mandatory characteristic belonging to B-geometrical proprieties. B-section must have B-slope, B-section function, and at least one of the considered materials. B-section function considers the variability of vertical and transversal section of a B-beam. B-mechanical proprieties determines mandatory the B-concrete compression strength, B-rigidity module, B-yield strength, and B-elasticity models of the involved materials. B-behaviors may be B-elastic or B-plastic. B-function section is required by B-inertia moment function, which is, in turn, required by the B-rigidity module.

Combination of commonalities and variability, according to adopted constraints, allows the configuration of a big set of different products of the same line. For coupled walls, many arrangements of products, such as: building models, mathematical models, coupled walls units, among others, may be configured and assembled varying materials, geometrical properties, and mechanical proprieties.

5. Conclusion and Future Work

GCM, introduced in this work, allows systematic delimitation and gathering of domain knowledge.

The set of functionalities referred to the life cycle of engineering systems (in general solutions), expressed in a generic way in this work, encloses the model used in the lifecycle of traditional engineering. For example in civil engineering, known analysis and design models suit in particular branches of the goal-characteristic model.

New analysis, design, and construction methods may be identified in the goal-characteristics model taking profit of variability and reuse.

GCM allows its fragmentation, in order to reduce the complexity of domain models, to analyse separately the context and the domain knowledge, to elaborate in real time domain views for optimize the process time and cache memory in interactive and incremental processes.

Different sets of functionalities are being used to construct generic GCMs adaptable to particular domains. The research continues for obtaining new innovative products related to de analysis, design and construction of reinforced and tensed concrete buildings. Software products for analysis and design, and a line of structural design plans is the priority.

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Enterprise Integration of Engineering Systems for Defence Related Projects

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Abstract. Defence Projects world-wide are undergoing a gradual transition from development projects to those involving integration of COTS and Military-Off-The-Shelf (MOTS) Systems. At the same time Requests for Tender (RFT) solicit Innovative Support Solutions to reduce Life Cycle Cost (LCC) over thirty years of operation. While there are defined processes to support both Systems Engineering and Support Engineering, these are hierarchical by engineering discipline and do not provide the means of architecting and trading off system design and support objectives concurrently. This study analyses the suitability of existing engineering processes and builds a model of the current state process set and artefact relationship and compares these with the international standards against the goals of reduced Life Cycle Cost (LCC). This reserach identifies the transitional needs and proposes changes to the Enterprise Business Management System processes, tools and work product templates to achieve concurrent system and service solution engineering.

Keywords. Enterprise integration, product service systems, commercial-off-the-shelf, military-off-the-shelf, life cycle cost, support solution

Introduction

Australian Defence Force Projects are undergoing a gradual transition from new development projects to those involving integration of commercial-off-the-shelf (COTS) and military-off-the-shelf (MOTS) systems [1], at the same time requests for tender (RFT) solicit innovative support solutions to reduce life cycle cost (LCC) over the service life, typically over thirty or more years of operation. While there are defined processes to support both systems engineering and support engineering, these are hierarchical by engineering discipline and do not provide an efficient means of architecting and trading off system design and support objectives concurrently. Often shortfalls of acquisition funding limit the adequacy of the support solution to sustain the system.

Current government thinking is to enter into performance based contracts to engage a prime contractor, that is fully responsible for managing all relationships with suppliers and sub-contractors. However, research has shown that effectiveness of this type of contracts depends on the relationship and system compatibility between customer and suppliers. The result is the risk of uncertainty in guaranteeing availability and capability of the system being support [2]. For example, the Hobart Class Air

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Warfare Destroyer (AWD) requires a well-defined support architecture for through life support system due in part to the complexity of the ship and partly due to the large number of stakeholders that need to interact to create an effective support solution for the systems [3].

This paper discusses an enterprise integration approach to adapting commercial organization internal systems to manage defence related projects in such a volatile environment is a complex and time consuming exercise as it involves multiple stakeholders, an understanding of the processes, determination of the requirements of the organisation and knowledge of available system models for supporting military asset's 30 year in service life.

1. Review of Current Enterprise Models

Enterprise models require an architecture framework to provide the foundation structure and constructs to build. The following literature review focuses on some of the common architectures used in industry and government agencies.

1.1. Department of Defence Architectural Framework (DoDAF)

The initial literature review identified that the US Department of Defense Architecture Framework (DoDAF) was popular, with some work further into Human Views including the NATO Human View [4] to complement Operational, System and Service Views. There are papers on specific uses of DoDAF to solve problems such as Information Security [5,6] and System Integration [7,8]; but little available as examples of service-system integration.

The DoDAF is the overarching, comprehensive framework and conceptual model enabling the development of architectures to facilitate the ability of US Department of Defense (DoD) managers at all levels to make key decisions more effectively through organized information sharing across the Department, Joint Capability Areas (JCAs), Mission, Component, and Program boundaries.

DoDAF serves as one of the principal means supporting the DoD under the Clinger-Cohen Act for the development and maintenance of information architectures [9]. The Act defines the term "information architecture" as an integrated framework for evolving or maintaining existing information technology and acquiring new information technology to achieve the agency's strategic goals and information resources management goals.

1.2. AUSDAF

Zhu et al [10] applied the Australian Defence Architecture Framework (AUSDAF), a variant of DoDAF to software system architecture. Architecture Evaluation is an approach for assessing whether a software architecture will be complete and consistent in terms of the system needs, especially the non-functional requirements (also known as quality requirements). Architecture Evaluation can be used at different stages of a project, and is an effective way of ensuring design quality early in the lifecycle to reduce overall project cost and to manage risks.

1.3. United Kingdom Ministry of Defence Architectural Framework (MoDAF)

The UK Ministry of Defence (MoD) Architectural Framework (MoDAF) [11] contains seven viewpoints: (1) All Views; (2) Strategic Views; (3) Operational Views; (4) System Views; (5) Service Oriented Views, (6) Acquisition Views, (7) Technical Standards Views. Key to this framework is the support for service information systems needed to support the operational system. The usefulness of these evolved frameworks may be limited as many of the adaptations have been incorporated into later versions of DoDAF.

1.4. TOGAF

The Open Group [12] produced the original version of TOGAF in 1995, based on the Technical Architecture Framework for Information Management (TAFIM), developed by the US Department of Defense (DoD). Enterprise Architecture can be used to denote both an entire enterprise - encompassing all of its information and technology services, processes, and infrastructure.

1.5. Interchange between Architectural Frameworks and Models

An issue with architectural frameworks is that their data models are extendable and may be implemented differently by different tool vendors who apply their selected methods. To transport architectural models between organisations it is necessary to align both the framework and the underlying data model. DoDAF OWL is the interchange specification for the DoDAF DM2 data model.

The Unified Profile for DoDAF and MoDAF (UPDM) is an evolving interchange standard for graphical interchange as well as current textual (XMI) interchange method. This method enables UK enterprises using MoDAF to exchange architectural information with US using DoDAF [13].

1.6. BAE Systems Enterprise System Processes

The Business Management System (BMS) in BAE Systems Australia is based on a combination of Life Cycle Management (LCM) a BAE Systems Project Phase/Gate Methodology, the Australian Standard for Defence Contracting (ASDEFCON) and the System Engineering Life Cycle Model (V-Model) organized by the ISO 15288 Process Areas. This approach considers the primary processes to be those required to produce a Mission System as well as those to develop the Support System. It should be noted that the BAE Systems definition of Product does not differentiate System and Service and it intended that the defined processes support either.

1.7. Stakeholder Analysis

Experience from recent bidding activities shows continued observations that the Support Team and Systems engineering teams work in isolation and information transfer takes place too late in the tender cycle. Consideration of the support solution is included but due to lack of understanding of the implications of performance based contracting, many contracts were made with a lot or risks [14]. Hence, the External

Stakeholder analysis was performed as a documentation analysis activity rather than through direct access to these stakeholders. This limitation was mainly because of resource and time limitations on this project (Figure 1).

Stakeholders that can be identified through this analysis include:

- The General Public – While the general public is not identified as a process stakeholder, the general public and its special interest groups have impact on the operations and support of defence products and services.
- The Warfighter – The user of the defence products is collectively termed the "warfighter" as the front line operator/maintainer/supplier of the product or service system. The warfighters opinions of fitness for purpose may be represented through official defence, political or media channels.
- Capability Acquisition and Sustainment Group – The Defence Materiel Organisation (DMO) was the contracting organisation of the Australian Government and managed the contractors such as BAE Systems for all Australian Defence project portfolio.

Stakeholder	Relationship	Key Needs	Interest Intensity	Influence /Power	Proximity	Urgency	Engagement Strategy
Warfighter	Operator/End User First Level Maintainer	Availability Reliability Timely Ease of Use	Highly affected by quality of support	Indirect but have influence via media	Distributed across Australia & Globally	High, Real-Time Issues	Voice of the Customer
Capability Acquisition & Sustainment Group	Capability Architect Acquirer	Performance Based Contracting	High Interest in Life Cycle Cost	High – Contracting Authority	Canberra Based	Low – long timeframes	Integrate Architecture Tailoring of ASDEFCON
System Project Office	Project Office Support Agency	Sustainment, Lice Cycle Cost, Upgrade,	High Interest in Cost and Schedule	Medium – Execute Contracts	Located on bases across Australia	Medium – Project Capability Timescales	Integrate with Architectural Systems Tailor Templates
Prime Contractor	System Architect /Supplier	Requirements Acceptance	Highly affected by OEMs	Control over Solutions	Typically Australian based	Medium – Project Contracted Timescales	Lead System/Service Architecture
Original Equipment Manufacturer	Supplier of Subsystems	Subsystem Requirements, /Acceptance	Low – Existing Customer Base	Control over Product & Data	Distant – Typically US or Europe	Low – Established Products and services	Obtain Product Data in format needed to perform analysis
Service Provider	Provide Services to Prime/OEM	Performance Criteria	High – Meet Performance Criteria	Control over response times	May be	High – Real time issues	Characterise Services

Figure 1. Stakeholder Engagement Analysis.

- Subcontractors – Subcontractors required to provide allocated subsystems of the Mission and Support Systems through a contract with the Prime Contractor. BAE Systems may perform the role of either a Prime Contractor or Subcontractor depending on the scope of the project.
- Service Providers – Service providers may be engaged as part of the Support Project or already exist as part of an ongoing support arrangement. These service providers require the skills to operate support processes as well as a means of improving their quality etc.

Further work could include direct external stakeholder engagement by interviewing representatives of each external stakeholder group.

1.8. Project Analysis

Project lessons learnt are a set of repositories of Learning From Experience (LFE) documents stored on the company central database. These are documented as both "positives" or best practices as well as "negatives" or things to avoid. The intention of these documents is to inform future bids/projects as well as provide input into improvement mechanisms. The following were extracted from the LFE documents:

Research shows that there is a market transition taking place along the Product-Service evolution towards servitisation [15]. New product development continues as does the need to support legacy systems. New defence projects either replace existing systems or undergo modification to achieve new capabilities or reduce life cycle cost. Traditionally, Acquisition and Support projects are separated, with the Logistic Support Analysis Report (LSAR) being the key artefact linking the two projects. Where both Acquisition and Support was performed by the same organisation, inadequacies of logistic support data could be remedied by the same organisation. Where they are separated, data deficiencies are exposed and may not be supported by Intellectual Property agreements.

For the purpose of analysis the projects have been categorised into four types to test the adequacy of Systems Engineering and Support engineering capability. Table 1 identifies these four types of projects and their relationships with different types of systems.

Table 1. Analysis of Project Types.

Case	Misson system	Support system	Support service	Opportunities
Developmental Mission and Support System	New Development Mission System	New Development Support System	New Support Service	Architecture Driven Performance Based
Unmodified MOTS	Unmodified Mission System	Unmodified Support System	Unmodified Support Service	Limited by Legacy Arrangements
Modified COTS/MOTS	Modified COTS/MOTS	Adapted Support System	Adapted Support Services	Reduce Life Cycle cost
Sustainment Only	Existing	Existing	Innovative Support Solutions	Reduce Support Cost

1.9. Process Relationship Modelling

There are numerous methods of defining and representing process. The common features of these representations are that they in some way describe activities to varying extents. Due to the different ontologies used to define process, this study was presented with a challenge of how to:

- Show that process elements are related to each other, even though they are described differently
- Understand the extent to which the existing defined processes work together or 'integrate' to achieve a common purpose.

For the former, the methodology selected to compare processes was the Supplier Input Process Output Customer (SIPOC) method from Six Sigma [16]. The extent to which processes are integrated involved the categorisation of the maturity of integration using Integration Readiness Levels (IRLs) by considering the process structure as a system and linkages between processes as interfaces. The quality of process integration was assessed using the criteria known as Integration Readiness Level [17].

1.10. Analysis of ASDEFCON

A SIPOC analysis was performed to identify relationships of ASDEFCON with BAE Systems BMS processes. This is needed as the ASDEFCON templates form the basis of the Contract Data Requirements List (CDRL) on a contract.

Since ASDECON was the customer's template, it was not feasible to directly relate to the BAE Systems Process. The SIPOC process representation was used to create "process equivalence". The analysis was performed on a small number of items to determine the extent of linkage between data items. The literature review did not discover any overall architectural framework under which ASDEFCON is defined. This does not mean it is non-existent, but further work may be needed in conjunction with the Department of Defence to establish whether such an architecture exists and whether it is maintained. In the absence of the availability of.

1.11. Analysis of Architectural Frameworks

To develop a specific enterprise model, reference to an existing proven architectural framework can improve the chance of success. In the United Kingdom the MoDAF provides the architectural framework for both acquisition and support. The UK Logistic Coherence Information Framework (LCIA) is expected to interact with MoDAF and provide a common set of processes and work products across both Government and the Defence Industry. The LCIA process structure covers the Systems Engineering and Support Engineering processes for both acquisition and sustainment.

In Australia, there does not appear to be any equivalent policy to either UK or US that would either mandate the use of architecture or provide the means of transfer of architectural information between the Acquirer (CASG) and the Australian Defence Industry Supplier.

2. Observations

The theoretical frameworks reviewed so far are required to be matched with existing engineering system processes [19] for transitioning. The following section describes some observations that can affect the implementation.

2.1. Architectural Observations

Large US based programs such as the Joint Strike Fighter (JSF) are mandated to use DoDAF. During the Tender activity it is difficult to maintain coordination between the development of the product solution and support solution. Architectural Design is a supported BMS process but is not well supported with tools/methodology and training, particularly in Support Engineering.

The customer of BAE Systems Australia is primarily the Australian Department of Defence with most projects contracted through the Capability Acquisition and Sustainment Group (CASG) using tailored versions of the ASDEFCON, which stipulated the content of external deliverables in the form of contract data. CASG produces Operational Concept Documents (OCDs). However, this approach focuses on the Mission System Capability rather than Support System or sustainment services. The Core/WSAF Model is not made available to Defence Contractors and "reverse engineering" to expose model relationships is incomplete.

2.2. Engineering Lifecycle Observations

Projects are expected to tailor the organisational common processes to suit their needs. This is expected to be through the approval of engineering plans. The Systems Engineering processes are defined around the V-Model Engineering Lifecycle. While these may be suitable for "greenfield" development projects they do not meet the needs of "brownfield" projects where segments of both mission and support systems may already exist and require integration and transition to sustainment.

The Commonwealth provided Statement of Work explicitly defines the required engineering phases and mandated reviews. For "brownfield" type projects the use of development oriented phases and reviews requires tailoring for recognition of previously developed product and service.

For service projects performing Engineering Support on developed and fielded systems projects extensive tailoring of process is required. The Engineering Support Process adequately address the range of Engineering process required to perform Engineering as a service.

2.3. Engineering Information Systems Observations

Engineering Information Systems are in place for Requirements Management and Configuration Management. There is a common data schema for Requirements Management (DOORS Schema). There is opportunity to extend the DOORS Schema into architecture and logistics information systems to suit Australian Defence requirements.

3. Proposed Architectural Approach

According to Harrison [20], architecture must have purpose. The architectural element of this framework considers architecture to be a whole of life concept rather than a phase within the engineering development activity. Architecture would be developed and maintained for different purposes. Elements in this architecture are:

- Business Strategy – The Business Strategy element of this architectural approach is aimed at aligning the enterprise to the business objectives, defence or other business Sevicescape, criteria for making decisions and understanding of assumptions and constraints. These collectively form the basis for ongoing project activities. The business strategy is supported by a Business Model, Business Data and the capability to perform business analysis.
- Characterisation of Existing Capabilities – For existing systems the architectural approach is to either integrate existing models or to "reverse engineer" existing products or services to be able to evaluate against the

capability architecture. Previous Verification and Validation data is used to determine fit to the capability architecture.

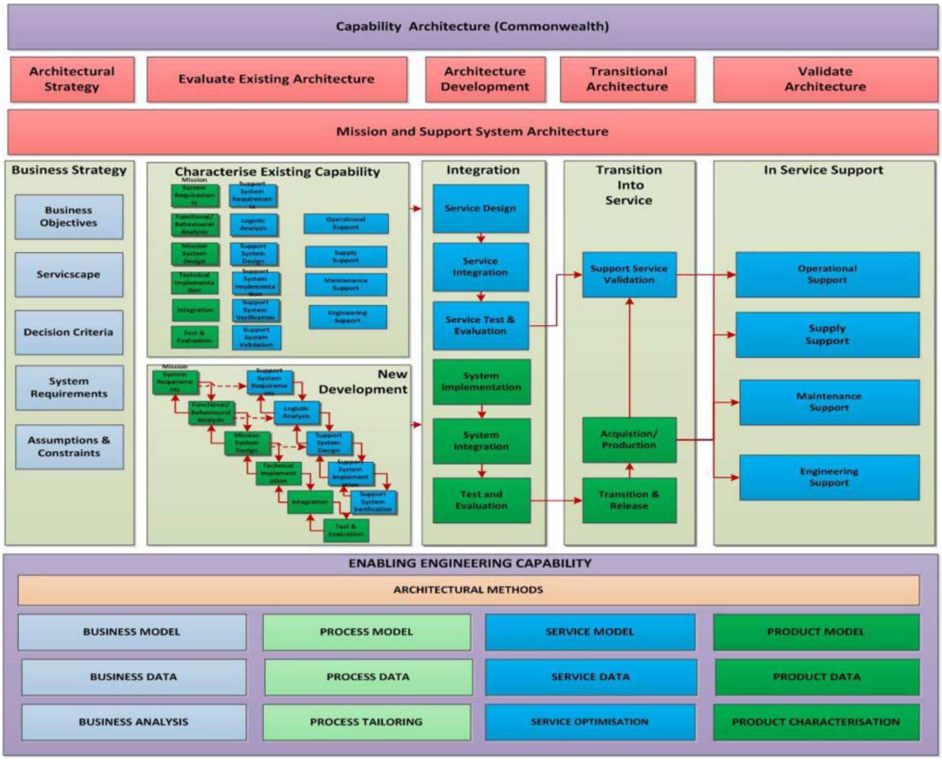

Figure 2. Proposed Architectural Approach.

- Integration – Once characterised and accepted as suitable, the products/services undergo adaptation and integration into the required product-service system. The maturity of this integration is measured through Integration Readiness Levels. Any new development elements are integrated with the adapted elements to form the new systems.
- Transition Into Service – The transition into Service utilises Project Views of Architecture to schedule the requisite elements of products and services for deployment and use. At this stage the product-service systems are used in their intended environment and undergo validation against the capability architecture.
- In Service Support – Throughout the sustainment period, product and service measures are captured and analysed against the metrics design to support performance based contracting requirements and form the basis of process improvement. Progressively, the capability architecture, system and service models are validated. As changes are undertaken the architecture and models are updated. Any potential change can be modelled prior to commitment to change to ensure changes will contribute to lower life cycle cost.
- Enabling Engineering Capability – The architectural approach requires the deployment of architectural frameworks, models and engineering systems as an integrated data system governed by a data schema. This is necessary to

ensure interchange of information between the architecture, models and metrics systems.

4. Conclusion

The proposed architectural approach provides a clear development pathway for migrating existing engineering system processes to a new support system architecture that is complete and adaptable. With change of project types from predominantly new development projects to a mix of new and existing system integrations and service projects, the approach to selection and deployment of Engineering lifecycle should reflect this change through de-emphasising the V-Model approach and forming new project templates based on project characteristic. Alternative engineering life cycles such as the spiral or incremental model should be supported by process, tools and training.

To facilitate the transition to servitisation, the project characterisation should allow for the response to be by the selection of services from the service process library. If product development is required, this could be accommodated through the use of a "product development service" In this way the distinction between a product and service can be applied at the appropriate level of the Work Breakdown Structure.

While it is expected to be significant variations in Mission System architectures, Support System and Support Service architectures for Defence align with the constituent support capabilities. An architecture template for support, consistent with the ILS Work Breakdown Structure (WBS) would allow current projects to initiate an architected support solution which can be linked to the Mission System architecture. From this early use of support architecture, successive projects could then evolve and improve the architecture to suit typical support solutions.

The Role of Solution Architect needs to be developed and skilled to the point where there are competent persons capable of applying Systems Thinking to the capability problem-space and generate the Product-Service architectural models can be used to support servitisation decisions at the early stages of a project, at least before any design decisions are made.

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Development of a Web Platform for Casting Process Selection

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Abstract. The choice of the right process for casting components is a complexactivity, and impacts directly on the design and manufacturing of the product. A single failure in the casting process selection can increase design and production time and, in critical cases, result in a collapse of the manufacturing and assembly of components. This process is usually based on guidelines scattered in the literature, or based on the designer's accumulated experience, but this action could be carried out by software containing a casting process database that can be employed during the product development stage, assisting the designer. In this context, our goal is to adapt a method for selection of casting processes previously developed into a web platform to support casting process definition. The adopted selection method uses Quality Function Deployment (QFD) and Design for Manufacturing (DFM) principles to provide a structure to support casting selection decision based on part features and process demand. The proposed software was developed for the Web using HTML and JavaScript, providing better usability than the previous format of the proposed selection method using spreadsheets. For validation, ferrous and nonferrous cast parts were analyzed using the proposed web platform. The results were compared with the selector provided by the American Foundry Society and with processes actually used in the industry. Thus, the results showed a good relationship with the other methods, also providing a quantitative classification (prioritization) of the results. In addition, this software supports the design of the manufacturing process by means of a checklist to adapt the part to the metal casting process presented to the designer.

Keywords. Casting process, Process selection, Web platform, Quality Function Deployment, Design for Manufacturing,

Introduction

Brazil is one of the ten largest producer of castings in the world, producing about two million and a half tons of molten materials per year. Furthermore, in 2014 the country produced an average of 10 tons a day. This industrial segment employs about 62000 people in almost 1300 companies. Most of these establishments are small and mediumsized, mainly created with investments from national capital sources [1].

The choice of the casting process directly influences the dimensional accuracy, finishing and mechanical properties of the component to be manufactured [2]. The right choice of the process usually ensures a reduced costs and production time, increasing reliability due to the lower probability of failure in production. Despite the existence of

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many methods for manufacturing molten parts, the designers tend to use materials and processes that they are familiar with, which is still a prevalent tradition. This action results in the deletion of processes and combinations of materials that could be more economical [3].

According to Swift and Booker [4], some designers are experienced and understand the limitations of each process they deal with; however, a lot of them do not understand the risks of a bad choice. An incorrect choice of manufacturing process results in substantial increase in design and production time, it also increases the chance of failure during the manufacture and assembly

Ashby [5] emphasizes the importance of specifying the functions related to the needs of the consumer or product operation. In addition, according to Lovatt and Shercliff [6,7] the selection of the manufacturing process is influenced by the material and the shape of the component. This relation between function, form and material is essential to understand the ways of selecting manufacturing processes [8,9,10,11].

It is possible to find in the literature several methods for process selection, including: expert systems, process information maps, rational methods, set of rules and multicriteria methods [7,12,13,14]. A particularity unanimous procedure among the selectors cited is a comparison of the part features with the parameters of each process. Darwish and El-Tamimi [13] and Setti [15] consider the characteristics with different weights, resulting on diverse importance for each of them. Only Swift and Booker [4], during the project development, consider the component requirements, at the end of selection process, in order to compare with the obtained requirements. Finally, Karthik et al. [14] and AFS [16] apply their respective selectors on a web platform. The Web format is independent of operation system and does not need a special configuration or download to work. In the web platform, users may have access from anywhere, at any time needing only a browser [17,18].

In this context, our goal is to adapt a method for selection of casting processes previously developed into a web platform to support casting process definition.

1. Metodology

The web platform was developed using HTML and JavaScript coding and was based on the Bringhenti et al [19] selector. The methodology embedded on this web selector combines QFD and DFM concepts and aims to choose the most appropriate casting process during the product design phases [20,21,22]. The interaction of these tools is described in the flowchart of Figure 1.

Geometrical characteristics of the component as well as requirements of the project are the start point to distinguish the material nature and to provide the component's functions and characteristics values [23,24,25]. Based on this input data, the selector is able to generate a ranking of casting process, pointing the most appropriate. To complete the selection, a Checklist is provided in order to correct the component's parameters, or to adapt the project to fit the feature's characteristics of the process in order to make the it more efficient.

Bringhenti et al. [19] proposes to differentiate between ferrous and non-ferrous metals, since some casting process can not be applied to both cases. The characteristic values which should be provided by the designer are: mass, minimum section thickness, draft angle, surface finish, dimensional tolerances, minimum lot and lead time. Due the fact that the dimension of the part is directly linked with the value of the dimensional tolerance, so it is necessary to inform the greater dimensional value for the desired tolerance.

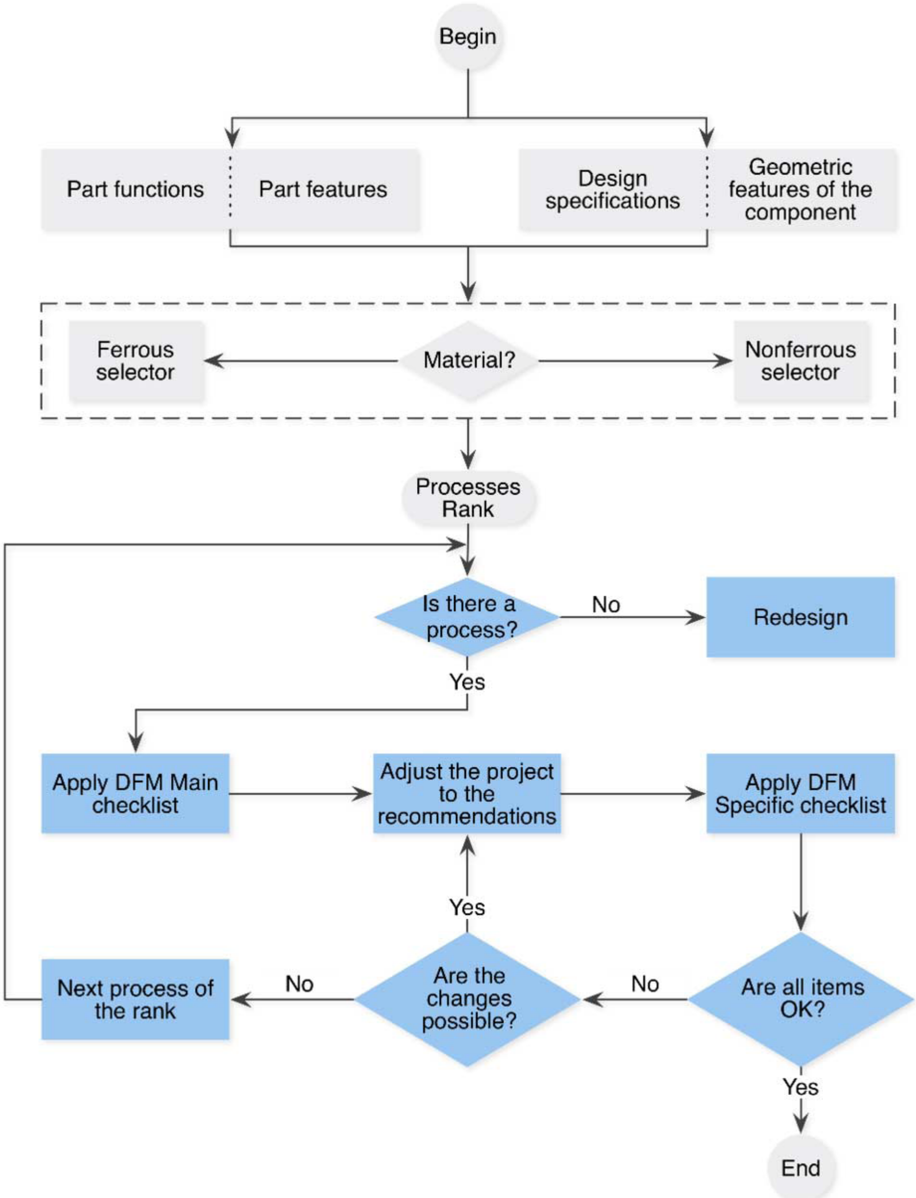

Figure 1. Selector operation flowchart integrating the DFM [19].

The starting point for the use of this selector is during the embodiment design of the product, which has already set much of the product architecture and some parts were selected as candidates for the casting process. In addition, it is also known its function and some desired design parameters (geometry, finishing, materials, etc.), which provides better suited information for the selector. The conceptual model used, shown in Figure 2, consists of two parts: (a) a Correlation matrix and (b) a Selection matrix.

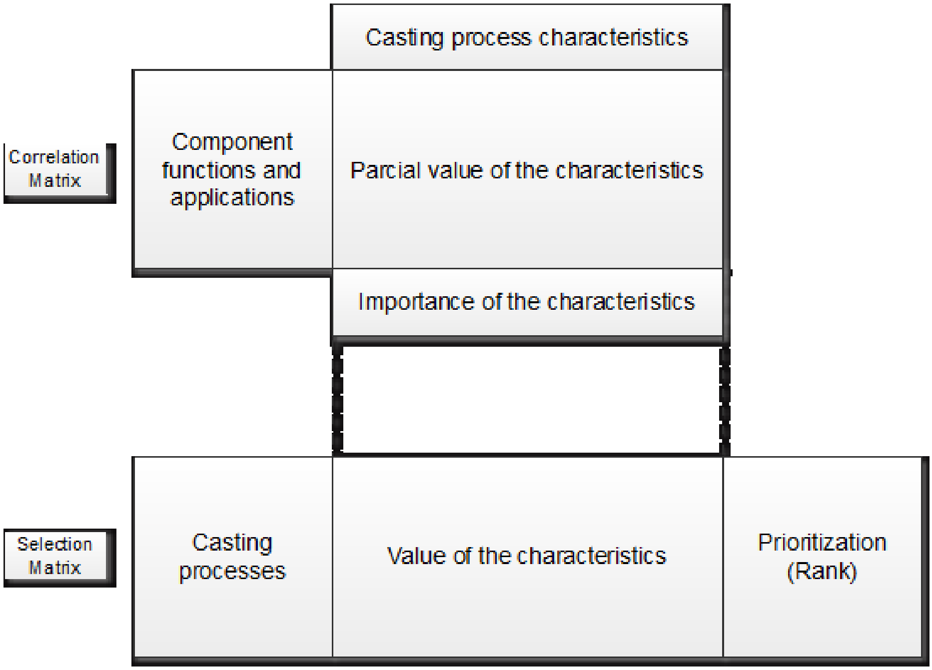

Figure 2. Selector operation flowchart integrating the DFM [19].

The correlation matrix gather the associations between component functions and applications, called "Description", with the casting process characteristics, in order to obtain the importance of the characteristics processes (mass, minimum section thickness, draft angle, surface finish, dimensional tolerances, minimum lot and lead time). In this matrix the correlation must complies with the scale ranging from 0 to 5, where 0 means nonexistent correlation and 5 means a very strong correlation. In the web platform, this matrix was concieved as an interactive table, shown in Figure 3, where the user can add and remove lines according to the number of functions and applications of the product, meanwhile the value of characteristic importance adds or decreases automatically in the last row of the table.


2 step: QFD (Quality Function Deployment)

Description	Mass	Minimum section thickness	Draft angle	Surface finish	Dimensional tolerances	Minimum lot	Lead Time	
Support springs and torsion- there are montage	3	0	3	0	3	0	0	-
Enter new description	0	0	0	0	0	0	0	+
Σ Characteristic's importance of the component	3	0	3	0	3	0	0	

Submit Reset

Figure 3. Correlation matrix of the web platform, based on QFD, in order to obtain the importance of the characteristic values.

In the selection matrix, to obtain the prioritization, the values of characteristics are compared with the casting processes capabilities. For each process characteristic, by Bringhenti et al [19] established four levels for the "value of the characteristics" namely: 1) Extreme minimum, 2) Minimum of 3) Maximum and 4) Extreme maximum. This values are matched with a database which is already built into the proposed web platform. To obtain the prioritization rank, the design goals are compared with the values of the characteristics of each casting process. From this comparison are determined indicators of capability ranging from 0, 1, and 2, where: 2 means design goal is between minimum and maximum value (within the usual limits), 1 means design goal is between the minimum and extreme minimum, or between maximum and extreme maximum (within the extreme limits), finally, 0 means design goal is above maximum extreme or below minimum extreme (out of process limits).

The ratio of each characteristic is then obtained by multiplying the value corresponding process capability (0, 1 or 2) with the importance of the characteristics obtained by the correlation matrix. Therefore, the grade for each case process is the result obtained by the sum of resulting ratios of the characteristics for each casting process (lines). The results are standardized in the range 0 to 10 (obtained by dividing it by the maximum value multiplied by 10) facilitating in this way the interpretation of the final result. If any process obtain index 0 in any feature, its final score will be zero, in other words, the process is unable to produce the desired component characteristics.

In order to consider the characteristics of the process since the beginning of design, and based on the DFM principles, it is also provided a checklist as a guide to help designers review their project goals. The checklist is a list of functions to verify and document the selection routine, to make this process organized and simple [19]. This tool should be used for the best process ranked and all the fields in the list must be checked. If the features are not in compliance, changes related to costs, physical and dimensional limits shall be adjusted until all items are checked. Using the checklist, the designer will be able to adapt the component that will be merge with the requirements of the ranked process, ensuring a better efficiency in the fabrication process. The Checklists are provided to download int he web platform in PDF format.

To validate the web platform, the obtained results using two components from the industry were evaluated and the results were compared with the ones employed by the industry and the AFS [16] web platform.

2. Evaluation of the web platform proposal using industrial components

For process selector validation it was used real parts applied in the local metalworking industry, described in Table 1, being one ferrous and another one non-ferrous. They are:

a) Planetary gear housing: component used in the automotive industry, where the planetary gears are engaged Planetary gears;
b) Gate valve: component used in civil construction to interrupt the water flow in an installation.

The item (b) of the Table 1 will be used as a model to illustrate, step by step, how the web platform works. First, the data input from the Table 1b is given by the user in order to fill the initial web page data.

Table 1. Components analyzed from the metal mechanic industry.

	a. Planetary gear housing	b. Gate valve
Part		
Material	Nodular cast iron	Brass alloy
Mass [kg]	17.38	0.191
Minimum section thickness [mm]	14	2.5
Draft angle [o]	0.5	5
Surface finish [Ra]	40	40
Dimension [mm]	225	28.4
Dimensional tolerances [mm]	±1.4	±0.3
Minimum lot [components per year]	300	20 000
Lead Time [days]	Not specified	Not specified

The gate valve is used in civil construction to stop water flow in case of leaking or eventual maintenance. The water pressure combined with open and close movement can wear internal components of the gate. Based on this information, functions and features of the gate valve were chosen to fill the correlation matrix (Figure 4): (i) Domestic use, (ii) perfect fit other connections, (iii) has a large scale production and (iv) do not have to be painted.

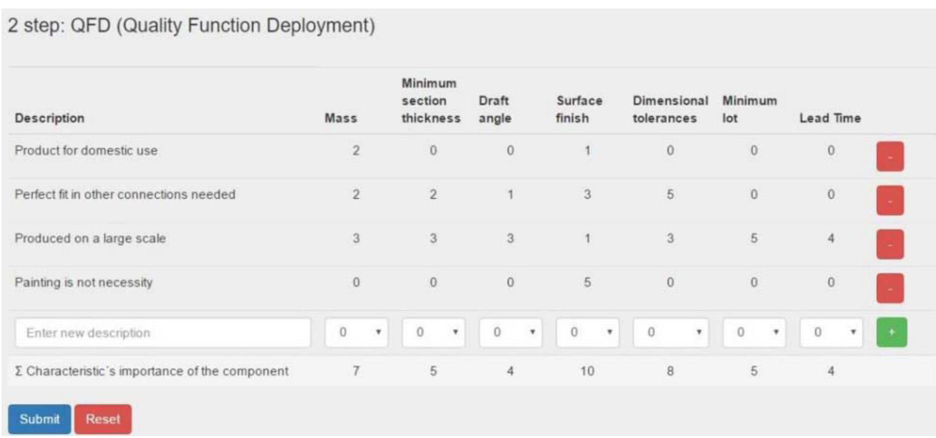

Figure 4. Matrix Correlation filled with values of the importance of each feature component of the gate valve.

When all inputs and importance are filled in the platform, the web selector is able to calculate each process grade, considering characteristics and comparing with minimums and maximums values.

Table 2 illustrates how the proposed algorithm calculate scores for each process, using the gate valve as an component and Investment Casting as a process example. The values in Table 2, columns C, D, E and F, are embedded on the platform and represent maximum and minimum values.

Table 2. Summary of the characteristics values and their importance for Investment Casting the gate valve part.

A	B	C	D	E	F	G	H	I
Features of the part	Value of [A]	Extreme minimum	Ordinary minimum	Ordinary maximum	Extreme maximum	Associated indicator	Importance [A]	Priority value of the charac-teristics G x H
Mass [kg]	0.191	0.0045	0.05	6.8	113	2	7	14
Minimum section thickness [mm]	2.5	0.23	1.04	NE	NE	2	5	10
Draft angle [o]	5	0	1	NE	NE	2	4	8
Surface finish [Ra]	40	0.73	1.14	2.86	NE	1	10	10
Dimensional tolerances [mm]	±0.3	0.16	0.28	NE	NE	2	8	16
Min.lot [components per year]	20 000	1	10	1760	NE	1	5	5
Lead Time [days]	NS	60	120	NE	NE	NI	4	NI
				Priority value for the process (not normalized)				63

The selector can generate automatically a table with the results, ranking process according to the grades calculated and standardised as illustrates Figure 5. The results of the web platform for gate valve are:

1. Investment casting (10,00)
2. Die casting (10,00)
3. Permanent mold – Low pressure (8,89)
4. Plaster molding (8,73)
5. Lost foam (7,62)
6. Ceramic Mold (7,62)
7. Permanent mold – Gravity (6,98)

To Planetary gear housing the results are:

Investment casting (10,00)
Cold box (9,90)
Ceramic Mold (9,49)

All the others processes were considered unable to fabricate the part with the desired characteristics (0.00).

Ranking of process

Order	Process	Grade	DMF Checklist
1°	Investiment Casting	10.00	PDF
2°	Die Casting	10.00	PDF
3°	Permanent mold - Low pressure	8.89	PDF
4°	Plaster Molding	8.73	PDF
5°	Lost Foam	7.62	PDF
6°	Ceramic mold	7.62	PDF
7°	Permanent mold - Gravity	6.98	PDF
8°	Centrifugal casting	0.00	PDF
9°	Shell Molding	0.00	PDF
10°	Green sand - manual	0.00	PDF
11°	Cold box	0.00	PDF
12°	Green sand- automated	0.00	PDF
13°	Squeeze Casting	0.00	PDF

Figure 5. Final ranking of the casting process for gate valve.

It is worth to notice the small difference between the obtained scores that fulfill the requirements for different casting processes. It demonstrates that the expertise of the designer is still necessary to evaluate process costs and availability for the company. Furthermore, every process has a final check list, based on DFM, attached in the web selector which must have all the fields checked by the designer to complete the selection process. If any field is incorrect, the project should be reviewed until all the fields have been checked. As a result, it allows the designer adapt the project, considering the process selected during development.

Finally, the Table 3 compares the results obtained in the proposed platform with the web selector provided by the American Foundry Society and with processes actually used in the industry. For the ferrous parts it is observed a high matching among the results, however it is not possible to reach the same conclusion for the nonferrous parts, where the platform results suggest the process used by the industry, but not with good marks. Difference in results is caused by the selection of the maximum and minimum values for each procedure, which has been made by comparing the values suggested in different bibliographies cited in Bringhenti et al [19] thus producing large gaps between maximum and minimum extremes. This particularity gives a good acceptance of the processes in the web selector when the characteristics of the components are compared with the platform database. A characteristic of the American Foundry Society platform (2015)[4] is, instead of creating notes, just indicate which process agree whit the parameters set by them, in this way the appropriate procedures for each component tested on this platform are represented in Table 3 by the letter ’X’. Furthermore, their platform alert users on processes operating in danger conditions, in other words, process which work in the reference limits. These processes are represented in Table 3 in red. When both selectors are compared, it is possible to relate the processes that received the lowest scores of the web platform proposed, with the processes that have received the letter ’O’ in the AFS Platform (2015)[4].

Table 3. Comparison between the proposed selector, AFS Platform (2015), and the processes used in industry.

		Planetary gear housing			Gate valve		
		1	2	3	1	2	3
1.	Green sand – manual						
2.	Green sand						.
3.	Cold Box	9.90	X				X
4.	Shell Molding					O	
5.	Ceramic mold	9.49	X		7.62	X	
6.	Investment casting	10	X		10	X	
7.	Lost Foam				7.62	O	
8.	Centrifugal casting						
9.	Permanent mold - Gravity				6.98	O	X
10.	Plaster Molding				8.73	X	
11.	Permanent mold - Low pressure				8.89	O	
12.	Die Casting				10	X	
13.	Squeeze Casting						

3. Conclusion

In this paper it is presented a web platform to support the choice of casting process. The web platform uses a previously developed method for selection of casting processes. It employes Quality Function Deployment (QFD) and Design for Manufacturing (DFM) principles to provide a structure to support casting selection decision based on part features and process demand. The proposed software was developed using HTML and JavaScript, providing better usability than the previous format of the proposed selection method using spreadsheets. The results showed a good relationship with the other methods, also providing a quantitative classification (prioritization) of the results. In addition, this software supports the design of the manufacturing process by means of a checklist to adapt the part to the metal casting process presented to the designer.

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Transdisciplinary Engineering: Crossing Boundaries
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A Transdisciplinary Process Oriented Framework to Support Generic PLM Implementation for Use by Small and Medium Enterprises

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Abstract. This paper describes the application of a transdisciplinary process oriented framework named Transdisciplinary Process Science and Technology, which employs the key concepts and techniques from diverse disciplines that deal with complex discrete event processes - namely Model Based System Engineering, Project Management, Business Process Management, and Simulation - as a base for the creation and implementation of generic Product Lifecycle Management supporting systems for use by Small and Medium Enterprises. The friendly and affordable applications created can be put to work together in a Product Lifecycle Management generic environment that is used to support the automated execution and management of the essential procedures in the development of short lifecycle engineering projects, as an alternative to complete and/or tailored Product Lifecycle Management and Business Process Management systems, which are usually costly, complex, difficult to customize and to integrate with the other organisations´s legacy software applications.

Keywords. Systems Engineering, Project Management, Business Process Management, Simulation, Transdisciplinary Process Modeling

Introduction

Transdisciplinary Process Science and Technology (T-ProST) designates a holistic world view, which consists of the integration of various disciplines that deal with complex discrete event process models [1,2]: (Model Based) Systems (Concurrent) Engineering (SE) [3,4], Project Management (PM) [5], Business Process Management (BPM) [6,7], and Simulation Modeling (SIM) [8,9,10].

Transdisciplinary process-oriented organisations or transdisciplinary Small and Medium Enterprises (T-SME) is another neologism used in this work to refer both to Small and Medium Enterprises (SME) and to research and academic institutions, who need to carry out systems concurrent engineering project developments of low-cost and low to mid-level complexity advanced technology products, submitted to severe

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constraints related to small sized teams, short project lifecycles and tight budgetary limitations.

T-SME project development is characterised by highly advanced but small sized technical engineering processes and more simplified managerial challenges, reducing its needs for sophisticated techniques and tools for the execution and management of the its system´s concurrent engineering lifecycle processes.

Nowadays, there is a wide array of Product Lifecycle Management environments available to choose from in the market. The majority PLM systems, nevertheless, are very complex PLM systems, which are costly and difficult to customise, and therefore it is difficult to find friendly and affordable PLM solutions in the market that can be customised and used to support T-SME. This entails the possibility that project developments of this nature might be conducted in a very amateur way, leading to project failure regarding scope, duration, cost and/or poor quality of the products being built.

The T-ProST methodology strives towards improving the modeling and seeking better and integrated engineering and management solutions for complex discrete event problems in general. This work presents the application of the T-PROST Framework for the implementation of generic PLM systems aiming at lowering the costs and improving the success rate of the so called T-SME projects.

The rest of this work is structured according to the following. Section 1 describes the T-ProST Framework´s Architecture. Section 2 identifies the problem and sets the overall scope of the research theme. Section 3 presents the conceptual modeling phase and the resulting reference meta-model. Section 4 describes the development of the specialised models, making use of the autonomous disciplines and their supporting tools. Section 5 refers to the use of the methodology to create basic or generic PLM environments, made by the ensemble of applications resulting from the implementation of the specialised models. Finally, the Section 6 presents the conclusions and future works.

1. The T-PROST Framework´s Archictecture

A T-ProST study is performed making use of a framework (T-ProST Framework) [1,2], consisting of three elements, which constitute the pillars of the methodology: 1) Knowledge Structure, made by the transdisciplinary hierarchical process model created (conceptual or reference model) and all additional information on the system being studied; 2) Implementation Method, which is the method used for the evolution of the models along their respective lifecycles; 3) Supporting Environment, which is made by the integrated set of tools used and their applications.

T-ProST Framework´s architecture is described in detail in article [1] and its three model building phases, namely Mission Definition, Conceptual Modeling and Model Development phases, used to create the specialised models and evolve them along their lifecycles, is shown in Figure 1.

The horizontal axis depicts the evolution of the models along their lifecycles. The rectangles correspond to transformation processes or simple activities and the rounded icons to data reposity of some kind, that is, complete models or objects and artifacts of some kind, which are gradually transformed along the complete process model lifecycle.

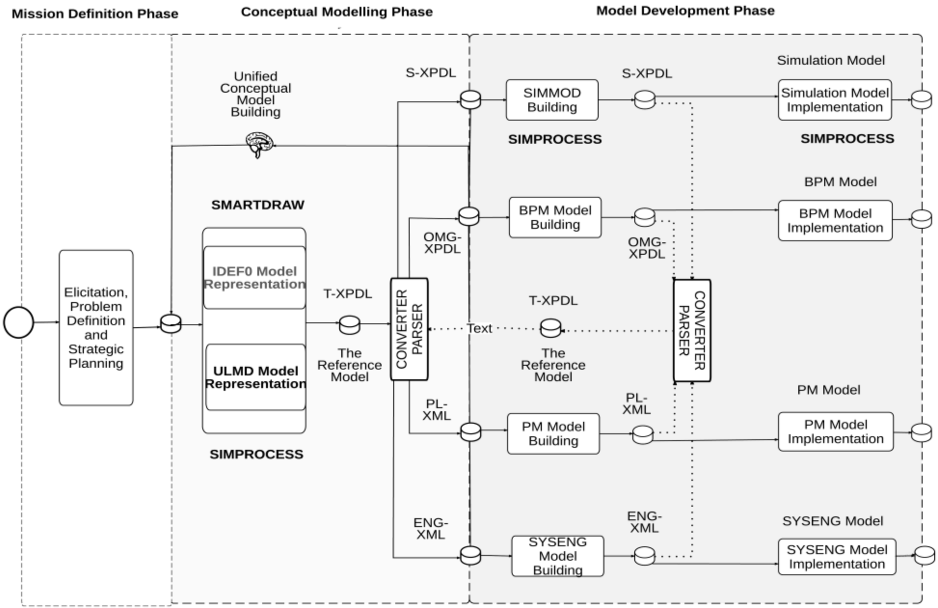

Figure 1. The T-PROST Framework´s Architecture.

The use of the T-ProST approach for the implementation of generic PLM environments is demonstrated hereafter in a stepwise way, by applying the methodology described in [1] to the design phase of the SE lifecycle.

2. Mission Definition

The mission definition phase of the methodology consists in identifying the problem domain for the application of the T-PROST Framework in a specific case study. The problem domain of interest for the case study conducted in this work is the design phase of the SE Lifecycle. The design phase of the SE Lifecycle is shown in Figure 2.

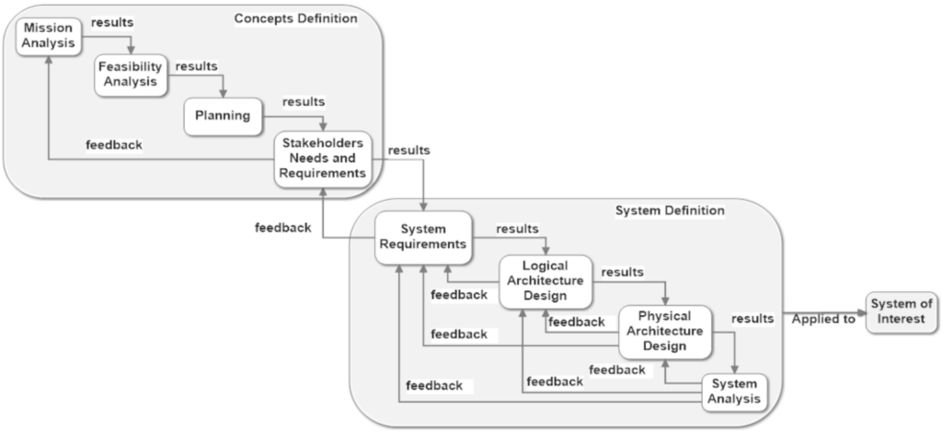

Figure 2. SEBoK[2] SE´s design phase processes modified by the authors.

The Design Phase of the SE Process Lifecycle is the phase of the project in which the system is being conceived and specified. It comprises the following two main processes: (1) the Concepts Definition process, which can be divided, on its turn, into four sub-processes designated by Mission Analysis, Feasibility Analysis, Planning and Stakeholders Needs and Requirements; and (2) Systems Definition process, consisting on its turn of four other sub-processes denominated Systems Requirements, Logical Architecture, Physical Architecture, and Systems Analysis.

The process Mission Analysis existed in SEBOK [4], but it was directed to the organisation´s mission definition and was replaced by Mission Analysis and Feasibility Analysis, defined according to ECSS [11,12], to introduce an assessment of the product´s conceptual model and its technical feasibility, before the start of the project (creation of the opening term or project charter). The macroprocess Planning did not belong to the original definition of the SE´s Process Lifecycle in [4], and it was added by the authors in order to adjust the model to project management standards [5].

Any enterprise that has (Model Based) Systems Engineering (MBSE or SE) as the main driver of its production processes may well make use of the concepts and definitions given in SEBoK, and the modifications above mentioned introduced by the authors, to describe the their product´s conceptual design phase, according to the structure shown in Figure 2.

3. Conceptual Model Building

The Conceptual Modeling procedure consists in the formal description of the model through the realization of two activities, namely The IDEF0 [13] model creation and the Reference Meta-Model Creation, using a graphical notation denominated Unified Lifecycle Modeling Diagrams (ULMD) [1,2]. This modeling phase is the subject of a detailed description in another article submitted by the authors to ISPE 2016 [1], and it will not be reproduced here, due to the lack of space and one is invited to refer to the referred article for more detailed information on the subject, if deemed necessary.

The complete reference meta-model comprises: hierarchically displayed component processes; their main actors or agents designated as entities; their respective individual process lifecycles with their time sequencing; the complete description of the inputs and outputs (artifacts and messages consumed or generated by the processes); the control rules and norms used for the transformations; the human and material resources or mechanisms used by the processes; the interactions and connections links displayed inside the lanes or crossing over their borders. All of that is used as a baseline model to evolve to the next phase of model representation, known as the Specialised Models Development.

Ideally, the input data for these models should be determined by people with previous experience in this type of project. In the absence of such persons, examples from similar projects available in scientific papers can be used. As a last resort, one can propose the use of random variables for estimating the activities´ duration in the simulation model and the use of these results for parameterizing the Project Management model.

A survey on the subject small satellites project development was conducted to assist in determining the duration of the phases of Concepts Definition and Systems Definition, with the aim of finding data related to the type of satellites being analysed.

As a matter of fact, little information was found on the complete configuration of the satellites, the precise definition of their real project network of activities, their number of participants, activities´ duration and/or associated costs and additional relevant data.

The lack of information on the design phase process generated from real project development scenarios led to another approach for model parameterisation. Instead of searching for data from previous projects, one decided to fix them taking into account the nature of a small satellite project development to be executed by a group of undergraduate in an university program consisting of an academic semester for the design phase and two to three years for the complete project execution.

The human resources estimated based on the approach adopted were set to be twenty participants, three project managers and seventeen product development engineers. Project managers also act as engineers, supporting the development of the satellites, if necessary. The group of engineers consists of seven doctoral students and ten master's students. The reference for the cost of these resources was assumed to be the values of monthly scholarships granted by CAPES for M.Sc. students (R$ 1,500.00) and Ph.D. students (R$ 2,200.00). The number of working hours per day was considered to be eight hours.

Some specifications were still originated from real scenario, such as the findings that the length of the Concepts Definition phase for the satellite AESP14 [14], developed by the Technological Institute of Aeronautics (ITA), was approximately twice longer than the Systems Definition phase. This parameter was used to define the time for other activities within each of these phases.

Three types of small satellites were considered for analysis, namely, satellites of types pico, nano and micro. For the duration of the activities, it was estimated that the total time of the Concepts Definition and Systems Definition phases for a micro satellite, more complex, would be six months, corresponding to the duration of one semester at a university. The remaining satellites, less complex, have the times of their activities reduced to reflect the lower effort involved in their project development.

4. Specialised Models Development

In the Development Phase of the T-ProST approach, the Reference Meta-Model is implemented into different applications, one for each of its component disciplines: (Model Based) Systems Engineering, Project Management, Business Process Management and Simulation Modeling. This section presents the Model Development Phase of the proposed System Lifecycle, related to the activities of Specialised Building and Implementation for each discipline.

4.1. The Systems Engineering Modeling and Application

Model-Based Systems Engineering (MBSE) [3] is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout product´s development and later lifecycle phases.

The basic designation of systems engineering model is used in this work to refer to the transformation (core production) processes through which passes the product, from conception to disposal (lifecycle), which is used as a basis for structuring all information available on the development of the system, documented as hierarchical processes.

The systems engineering model is a "descriptive" model and it makes use of the IDEF0 diagrams and of the reference model as its structural element. The systems engineering model, nevertheless, extends the descriptive information on the model far beyond the data in the IDEF0 diagram notation [13], such as inputs, products, resources and controls pertaining to the activities, and the workflow of processes represented in the reference model.

The systems engineering model shall provide information on the artifacts that are generated over the system lifecycle, as well as keeping control of system configuration as a whole, that is, the final systems engineering model represents the most complete description of the system being developed. Another important observation that needs to be made is that this type of model is a "descriptive model", that is, it is not intended to be executed as a process, it is intended to document the system with the complete information on its product development lifecycle, similar to a "recipe" on "how to produce the system", under an engineering point of view.

A software tool, denominated Smartdraw® [15], has been used to support the systems engineering model building and documentation. The use of Smartdraw® turned out to be a very friendly and efficient way to create graphical representations to document the systems engineering model of the complete product development lifecycle.

The other types of models described in the following are "process models", that is, they also describe the evolution of the product along its lifecycle, but they are "executable", that is, they are applications used to support the management during real systems project executions.

4.2. The Project Management Modeling and Application

The project management aims to plan and coordinate the necessary activities to provide a satisfactory product, service or business venture, within the limits set by the schedule, budget, resources, infrastructure, human resources and technology available.

The modeling in project management is considered as the application of project management techniques using a process-oriented view [4], supported by software tools, to expand the SE model with the necessary activities related to the management of product development throughout the entire product lifecycle.

The specialised project management model is created based on the reference meta-model representation in ULMD diagrams. The sequencing of activities (serial or parallel) in the project management model follows the same pattern already established in ULMD models. The feedbacks were considered as complementary activities at the end of each process. The time spent in feedbacks was considered as approximately 30% of the original total time spent in the process as a whole since the time required to review an activity previously performed is shorter than the original time.

The building / implementation of the Project Management specialised model makes use of the Projectlibre [16] environment, an open source tool, which presents itself as an alternative to Microsoft Project® [17]. An example of the Projectlibre graphical interface showing examples of activities and their respective durations, allocated resources and sequencing between them can be seen in Figure 3.

The sequencing of activities (serial or parallel) in the project management model followed the same pattern already established in ULMD models. The sequencing of activities in Projectlibre is accomplished by identifying the predecessor activity of each activity. The activity feedbacks were considered as complementary activities at the end of each process. The duration of each activity was adjusted so that the durations of the Concepts Definition and System Definition phases were in accordance with the previously specified durations.

Twenty resources were created in Projectlibre. Each resource was given a name with the first letter corresponding to one of the letters of the alphabet, to facilitate the allocation of activities. These resources were allocated to the activities in Projectlibre.

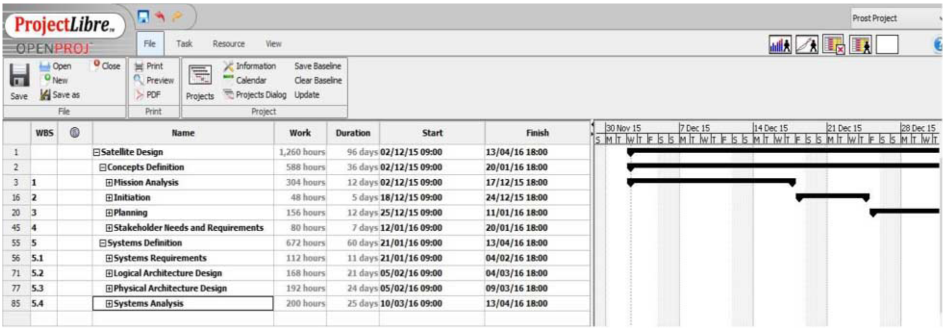

Figure 3. Projectlibre: support environment for the building of the PM model.

This allocation followed the indications established in the ULMD reference models. For example, the Mission Analysis process contains two columns, engineering and management, each one posessing its own entity´s lifecycle processo and separate flow of control. Management activities should be performed by project managers only, but engineers and managers are allow to perform engineering activities (managers here are senior employes or professors and they are capable of executing all kinds of activities).

With this approach, one can determine the number of hours of each activity, as well as the total number of hours for the project as well as its cost. The Projectlibre support environment also allows the visualization of details of the use of resources, showing graphs of changes in the cost of a given resource throughout the course of the project.

4.3. Business Process Management Modeling and Application

BPM is a structured and systematic approach for conducting modeling, analysis, automatic execution and control, management and continuous improvement of processes used in the product engineering and production management of complex product and services [5,6].

Business Process Modeling is the main activity associated with the initiatives to improve Business Process Management (BPM), because it deals with the way the enterprise organizes its production and management processes used for the development of its products and services. It allows a better understanding of its processes, their analysis, simulation and their improvement or optimization. The processes are represented making use of models, commonly created with the GUI interfaces of special computer tools developed for this purpose with different sophistication levels, making use of a special diagramming technique known as Business Process Diagrams (BPDs).

BPDs are just the start of a BPM project lifecycle. Their modeling tools are usually integrated with more complete development environments known as Business Process Management Systems (BPMS), which gives support to the complete process model lifecycle in studies carried out in Business Process Management, providing a complete environment and the development of applications that will act as a part of the real time mechanisms of real systems operation, monitoring and control. These applications contribute decisively to the continuous improvement of the process models and systems performance. Its model based approach allows for joint and collaborative teamwork among the professionals of the Information Technology (IT) area, through the entire product development lifecycle. The complete set of software tools to support the BPM methodology is known as Business Process Management Systems (BPMS) [5,6].

The BPM tool chosen to create the Business Process Diagrams (BPDs) was the BIZAGI Modeler [19], which allows for friendly graphical manipulation of the models and their exportation to other existing proprietary tools by means of XPDL model representations. The models created may also be simulated in order to analyze its adherence to the reference model, verify its consistency and evaluate model improvement strategies.

4.4. Simulation Modeling and Application

Simulation can be seen as the study of the real system behavior by means of exercise models. A model incorporates features that allow representation of the actual system behavior. It can be used when the solution of a problem is very expensive or even impossible through experiments, or when problems are too complex for analytic treatment. When using simulation coupled with stochastic characteristics, systems can have their behavior represented with greater fidelity and realism.

The use of SIM in T-ProST follows the traditional definition of simulation with the remark that one is addressing the aggregate of the processes representative of the systems engineering and of the organization management lifecycles [7]. The only special feature is the use of the reference meta-model, represented in the ULMD notation, to base model development in the proprietary simulation system offered by the different manufacturers. The complete simulation application requires the creation of the facilities needed for the experimentation (design of experiments) and of any other additional features for analysis and presentation of results.

In this work, only the Concepts Definition phase was modeled and studied for analysis purposes. In the creation of the specialised simulation model, the reference model in ULMD was used for the mapping of the processes into the Simprocess® GUI interface [18], and the introduction of Activity Based Costing (ABC) estimates.

5. The Integrated Generic PLM Environment and Global Assessment

The Global Assessment makes use of the generic PLM environmento to perform the joint or integrated assessment of the results produced by the individual specialised models during their independent execution, aiming at the consolidation of the results.

The potentialities of the T-PROST Framework for the implementation of generic PLMs environments was demonstrated by means of a pilot project, conducted by the students of the postgraduate Course on Systems Engineering and Management (CSE-331/ETE/INPE).

The case study was developed as a class project, making use of the following support tools: ProjectLibre [13], to support project management applications; BIZAGI [18], to support the application of BPM techniques; and SIMPROCESS [19], to build simulation models and conduct their analysis of results.

The resulting PLM environment was created with the application of the above commercial off-the-shelf systems, which were put to work together as an integrated environment of interoperable tools, and used to support the product lifecycle engineering and management processes.

The main reason for choosing these tools was their availability in the form of open source or low cost academic licenses. They can be easily substituted by similar systems, since the great majority of them can cope with the implementation of the specialised models described in the SE, PM, BPM and SIM categories presented in this work.

After performing the general assessment activity once, several repetitions of this procedure can be made, if necessary, until one is assured that the initial requirements established for the product lifecycle management process model satisfactory operation have been reached.

6. Conclusions and Future Researches

The present work shows the potentialities of the T-PROST Framework to create generic PLM environments. The transdisciplinary process-oriented methodology was used to develop applications, which were put to work in an interoperable way, aiming at the integration and the exploitation of their complimentary advantages, to create an environment capable to support the design phase processes of the systems concurrent engineering lifecycle.

The environment created is seen as a valuable asset for use in real applications, in a scenery in which few support COTS software systems exist for this purpose. The similar systems known to the participants (proprietary PLM environments), which could have been be used to perform similar functionalities, were considered to be too complex, too big or too expensive. These systems have not been designed for the less demanding level of complexity, regarding both the technical engineering requirements and the managerial aspects, involved in small satellites project developments.

In particular, the pilot project conducted by the students of the CSE-331 postgraduate course on systems engineering and management has demonstrated the potentiality of the methodology and its supporting environment to make a great jump start in the quantity and quality of the knowledge acquired about the conduction of small satellites space missions.

Other case studies have been previously conducted on other types of discrete event problems, such as a steelworks problem used as a class project, which is an example of a serial production process, typical of the SIM study area. Another example of application was on a house construction process, typical of the PM study area, which has been modeled and studied as a hybrid PM and SIM problem, showing the diversity of systems that can be represented using the notation.

Another direction for future research is to use the methodology to create generic PLM made from different bundles of systems, with Simprocess used as the central component for the creation of the reference meta-models, which can be exported/imported in a variety of Extensible Markup Language (XML) and XML Process Defintion Language (XPDL) formats, used by the different proprietary tools existing in the market. Finally, the creation of mechanisms to facilitate the execution of the global analysis might also be the subject of further research endeavors.

In summary, the approach seems to be very promissing, and further publications will report on the advances of T-PROST. The expectation is that it will evolve to become a complete mature methodology with different types of supporting environments, capable of application in a variety of real scenarios from different study areas, and to deal with complex discrete event process problems in general.

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Toward Systematic Software Reuse: From Concept to Modular Software Implementation

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Abstract. A considerable part of the development effort of systems nowadays is related to the design and implementation tasks of the software components of the system. The main motivation for this work is the expected benefits from a successful implementation of systematic software reuse by the organization, as described in IEEE 1517 - 2010: Increase software productivity; Shorten software development and maintenance time; Reduce duplication of effort; Move personnel, tools, and methods more easily among projects; Reduce software development and maintenance costs; Produce higher quality software products. This work will focus attention on what is needed for an organization to establish systematic software reuse from a process and standards point of view, to repeatedly exploit reuse opportunities in multiple software projects or products, and on how this can be implemented and harnessed on real world projects. To accomplish this, some development cases were selected from the available literature and effective approaches to the execution of tasks from processes of the Atech product life cycle model were exercised in two case studies. The application of effective approaches to development proved to be challenging, as whole new set of tools and processes are being demanded to adress the complexity of modern systems.

Keywords. Software reuse, architectural mismatch, configuration management.

Introduction

The technology market of today demands the development of large systems, with increasing complexity, within a shorter development time and with assured quality. This demand-pressing market requires from system providers high responsiveness and great flexibility during development of solutions. As a result, productivity and quality issues are increasing in the software development and implementation phases. The resulting impact on development intended for software intensive systems is significant. Higher product throughput and quality may be achieved by the successful construction of systems from already developed and tested components; a development concept introduced into the software engineering arena during the late 1960s [1,2].

This work intends to characterize the context and issues addressed in the challenge of achieving practical systematic reuse at Atech S.A. during development of a software intensive simulation system. To accomplish this goal, this note presents the standards view of processes that supports the systematic reuse of software; a

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bibliographic review of the software reuse challenge from the software architecture & components points of view. In particular, the use of a component-based development method [2,3] is applied to solve the reuse problem in-house, where components are managed through building block specification, classification and retrieval.

The difficulty inherent in the reuse problem can be briefly described by the mismatch of interface of the two software components depicted as *A* and *B* in Figure 1: they don't work together if they mismatch, i.e. if they were originally designed to work under distinct architectural assumptions.

1. Software Reuse from the Standards' Point of View

Software reuse, as stated in IEEE 1517-2010 [4], is concerned with the creation of new products from existing software and systems. This is not restricted to the creation and use of a library of assets, however. To achieve the successful reuse, activities related to the reuse must be included in the life cycle processes used to create the reuse assets. It is important to note that the term reuse considered here conveys the meaning given by the IEEE 1517 definition as *systematic reuse*. Simply stated, systematic reuse is the avoidance of multiple versions of otherwise common elements. From the organization point of view, what is desired is to repeatedly exploit reuse opportunities in multiple software projects or products.

In this work, our focus is set on the integration of reuse in software specific life cycle processes, although the organization may benefit from integration of reuse in the whole system life cycle processes. The software specific life cycle processes may be decomposed into Software Implementation and Support Processes.

Software Implementation Processes comprises the activities and tasks performed by the developer when developing software products with reuse of assets. These standards include the activities for implementation requirement analysis, architectural design, detailed design, construction, integration and qualification testing. These processes will not be reproduced here for the sake of brevity. This listing also presents additional expected outcomes from each processes and tasks added to some activities. Refer to IEEE 12207-2008 [5] to obtain a better understanding of the processes, tasks and activities that form the baseline to which the added features refer to.

Additional tasks also apply to the development process. These are the Software Support Processes, [4]. Application of these Support Process is explained in Section 3.

Figure 1. Composition of two software components and the problem of component interface mismatch.

2. Software Reuse from the Practitioner's Point of View

The inherent difficulties that arise when building software applications, see [6] for example, from existing parts are not new. In 1995, Garlan and co-workers [7] identified

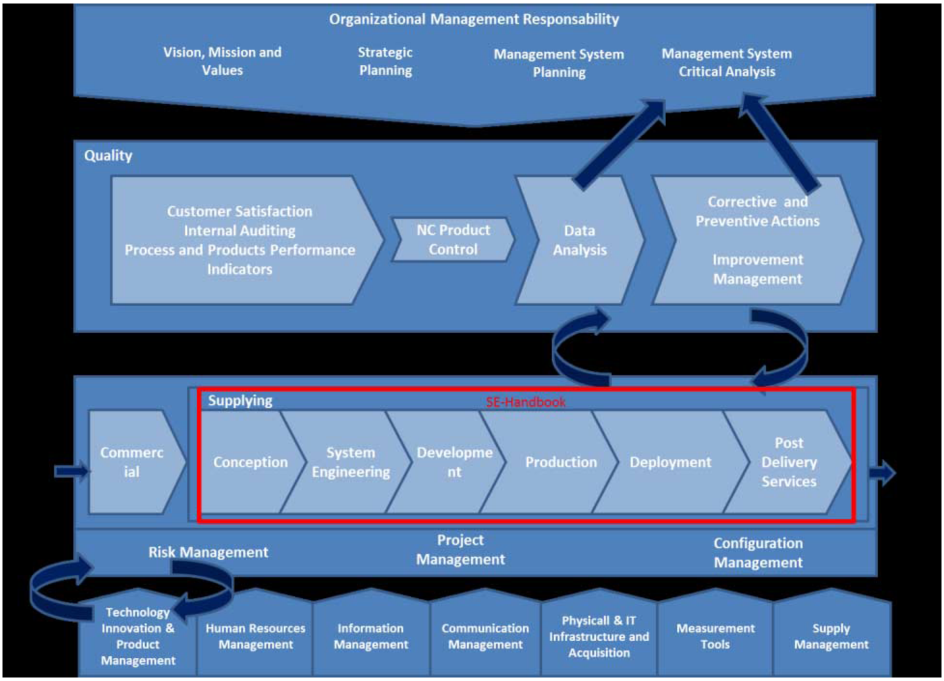

Figure 2. The Atech System Life Cycle Model.

what they called the *architectural mismatch*. In their work, the traditional solution to the reuse problem was reviewed and the root cause of the unsuccessful approaches identified, [7]:

> *"Clearly some blame can be attributed to the lack of existing pieces to build on, or our inability to locate the desired pieces when they do exist. Over time, we may expect progress in this area through the creation of more and better component libraries as well as improved mechanisms to access their contents…*
>
> *... even when the components are in hand, there remain other fundamental problems that arise because the chosen parts do not fit together well. In many cases mismatches may be caused by low-level problems of interoperability, such as incompatibilities in programming languages, operating platforms, or database schemas. These are hard problems to overcome..."*

In another work, Garlan and co-workers [8] showed that the system was built from parts that were designed to be reused. Developers of both, parts and system, were aware of implementations details and the implementation language. The execution platform did not originate new issues, as all the parts were written in C/C++. System development began with the expectation that a single person during a 6-month period would accomplish the job. It soon became apparent that their endeavor would require 2-year of work with 5-person-year. With far longer development time, the expected system with the expected functionality was built, but the *"...resulting system was sluggish, huge, brittle, and difficult to maintain*", [8]. The usual excuses to development failure did not apply to this project. The parts were engineered for reuse, the implementers were skilled, the requirements and functionalities were well known, the development team was familiar with the source code and implementation languages and the parts were used in accordance with their functional purpose. Fourteen (14) years later, in 2009, Garlan and co-workers [9] revisited the problem and contrary to their expectations, they showed that this problem still persists and new issues were added to this landscape. These issues were summarized as: excessive code size, poor performance, need to modify external packages, need to reinvent existing functions, unnecessarily complicated tools, error-prone construction process. Once more they were "*failing miserably*" to employ reuse to its fullest.

The architectural mismatch may be defined, in a simplistic form, as the intrinsic incompatibilities arising when attempting to connect and make operate together the software components that were originally devised under distinct architectural styles. To overcome this mismatch, adaptations need to be present to connect reusable assets that were built to be part of solutions in different architectural styles. Refer to [9] and the references therein for a detailed explanation of architectural styles. Shaw [10] presented the architectural mismatch as a packaging problem and identified a set of integration patterns. Although convenient, this approach introduces a lot of compatibility code in the application.

To expose the architectural mismatch, a simple system architectural model should be used. According to this simple model, an architecture is composed by Components – primary computational and storage elements of the system – and by Connectors, that do not in general correspond directly to compilation units, see Fig. 1. From the above definition, four categories of architectural mismatch can be identified, details in [9]:

1. Assumptions about the nature of the components: infrastructure-assumptions; control model-assumptions; model-assumptions about how environment will manipulate data managed by a component.
2. Assumptions about the nature of the connectors: protocols-assumptions about the patterns of interaction characterized by a connector; data model-assumptions about the kind of data that is communicated.
3. Assumptions about the global architectural structure: Related to the topology of the system communications and the presence of particular components and connectors.
4. Assumptions about the construction process: In many cases the components and connectors are produced by instantiating a generic building block.

The above mismatch categories proved helpful during conception and application efforts of the solution targeting SW reuse to the development processes.

3. Application of an Effective Approach to Development Processes

The task of making developers aware of the tasks and activities to be performed to achieve the systematic reuse in the organization is not a simple one. For this initiative, a more agile and responsive approach was adopted, given a single assumption was made to make small but effective interventions in a running development project. This approach considered a compromise solution, harmonizing good development practices and rigid application of norms.

In this section the development project selected for this work is briefly introduced and its relevant characteristics are described. The approach to implement the changes for systematic reuse and the stakeholders directly involved in this work are presented. A brief description of the CM processes implemented at Atech is described first followed thereafter by the application IEEE 1517 standard goals, presented in [4] as lists of Implementation and Support Processes, in the Atech context, in Section 3.1.

The running development project selected for this initiative comprises the development of a simulator to stimulate the Atech Air Traffic Control, or ATC, solution for training purposes. The complete ATC solution of Atech comprises more than 50 modules operating in distributed environment and with very different deployment combinations to provide services and support to control, training, planning and simulation activities. The modules were developed by different teams and depending on the constraints in different technologies and programming languages such as C, C++, and Java. This solution comprises large blocks of Atech expertise knowledge, and this knowledge is already coded into software blocks with very similar application, but originally intended for slightly different business domains. From the functionality point of view, almost 60% of the solution could be reused. The server side of the available component candidates for reuse is coded in C programming language and the available GUI component candidates for reuse are implemented in C/C++ (Motif) and on Java platform.

Tasks and activities were prioritized with emphasis on the software components design and on the control over components versioning and usage (configuration). To enforce the application of the recommended practices and to be more responsive to the needs of changes, an architecture office was created to perform the design of subsystems (system architecture design) and the design of the software components. The architects allocated to this office were also responsible for the detailed design of the components, selection of tools to support and automate repetitive tasks and give implementation orientation to the software developers. All the support needed to the configuration management of the software components was given by the Atech CM – Configuration Management – area. This close relationship was fundamental as the CM supporting area had to change some procedures to allow more fine grained control over the source code, building procedures and binary asset versioning.

From the configuration management point of view, the practice adopted in Atech is in accordance with the definition given in the Configuration management guidance military handbook [11], as a *"management process for establishing and maintaining consistency of a product's performance, functional, and physical attributes with its requirements, design and operational information throughout its life."* It is supported by four processes to establish and maintain this consistency: Configuration identification, Configuration Control, Configuration Status Accounting, and Configuration Audit. Refer to [11] for in-depth description of how each one of associated processes work in configuration management.

Configuration Identification is the process that permits to identify the system, its subsystems, modules, related documentation and configuration items. A configuration item is a part of a system that has a specified function and has its development individually controlled. Normally those items are primary items (modules) that will be reused in many projects and critical items but they can also be items used in the installation of the product and items that a client desires to control. In a hardware-software system, software is always considered a configuration item. Another function of the configuration identification is the creation of unique IDs for version and tags to allow the development team control its advancement and know what was delivered to the client. Tags are snapshots of a moment of the project that can be used to store, access and recover data generated on that particular point in time.

Configuration control is the coordination of all the asset changes that occur in a project, as well as all new versions that are created by these changes. It has great impact in the reuse of software since it allows the development team to track the impacts of each change of a module on every system configuration that may depend on it. Additionally, configuration status accounting is the process where all the data generated by the project is stored, accessed and recovered if needed. The status accounting store the data in the form of tags and baselines so a developer can restore its work form a predetermined moment in time, or a client can always recover the exactly same data for a product.

Finally, the configuration audit is the configuration analysis of all that was done so far. It inquires whether functions observed during the beginning of the project were applied at the end of the project, if the physical product is the same as the one documented or, if not, whether all the changes were accepted and registered. In a way, it is a final analysis given by the development and configuration management teams.

3.1. Results of Application of an Effective Approach to Development Processes

The following paragraphs detail application of the reuse approach as described in IEEE 1517 [4] to process tasks in software development processes. The application of Implementation Processes is listed first.

Software Implementation Process:

- life cycle process model: the Atech system life cycle model is already defined and shown in Figure 2. Phases are defined according to the organization management view with the related milestones and decision gates. For the design and development processes, tasks and activities are already performed in this framework, tasks and activities related to the reuse that were performed are already in accordance with this life cycle model.
- standards, methods, tools and programming languages: tools and languages for the project were carefully selected; for the sake of brevidy these are not listed here. Special emphasis is given to the adoption of the NAR plugin to the Apache Maven tool. This plugin gave the needed support to the definition of software components based on configuration of configuration items, or CIs, in an hybrid environment with components developed in C/C++ language and in Java language. Further details on this tool can be found in a description of the use of this tool in the LHC at CERN [12].
- communication issues: in this work, the communication mechanism is still informal and highly relies on the communication skills of the members of the architecture team.

Software Requirements Analysis Process: although not the main purpose of this initiative, this process had to be addressed as the project control and audit procedures relies on artifacts related to the software specification and traceability to requirements.

Software Architectural Design Process: all the tasks were performed by the team of architects. The identification of subsystems and system elements, the messages and interfaces gave sufficient information to setup the system domain architecture. In this phase it was possible to identify the configuration items that were part of the solution. In this process an architectural style, based on data distribution services specified by the OMG, or the Object Management Group, was chosen and, from this point on, all the assets were designed to play their roles in this integration environment.

Software Detailed Design Process: the tasks related to the detailed design were also performed by the team of architects. During the realization of some activities it was identified that new configuration items could be defined and with the support of CM staff it was just a matter of creating new CIs in the overall project structure.

Software Construction Process: the software design was done with testing in mind. Wherever possible, unit testing was implemented and through the continuous build/integration, supported by the tools considered for development, the build process was continuously exercised and enhanced.

Software Integration Process: this process was simplified by the fact that all the assets, such as the SW components themselves, were designed for reuse in a very specific architectural style. The interfaces could be separated in compiled binary configuration items and each system element could be described as a configuration of CIs, and the system itself could be described as a configuration of system elements. This represents the adopted solution to problem in Fig. 1.

Software Qualification Testing Process: This process and its specificities were not addressed in this work.

The application of the Support Processes of [4] is considered next.

Software Documentation Management Process: Document reuse was a goal at first, but the obsolescence and availability of software applications to edit and update old documents made this impossible to do. Diagrams had to be redrawn.

Software Configuration Management Process: The process of configuration management is already running at Atech, as shown in the previous session. It was needed to add support to the management of binary assets, in order to guarantee the reconstruction of a given build environment (compilation) and in order to allow the construction of configuration without the need to recompile all the modules every time that a new version of the system is generated. The main difficulty was the hybrid development environment with C, C++ and Java modules.

Software Quality Assurance Process: This process and its specificities were not addressed in this work.

Domain Engineering Process: The application domain was identified and an integration framework was developed.

Reuse asset Management Process: A formal process is still not established, but the requirements for the activities and tasks for this are being gathered.

Reuse has been observed and validated at Atech with software components reuse independently realized by different development groups and by independence of component version management through the appropriate tools. In particular, the composition of two components of Fig.1 is a binary used as the data distribution mechanism. This binary is a CI and serves as a component interface even for hybrid systems, i.e. systems developed under different platforms (e.g., C/C++ and Java).

4. Application to Development Case Studies

A conceptual framework devised at Atech for the development of complex, software intensive systems. It embodies the idea that complex systems are the sum of smaller and simpler parts, or system components. This platform also borrows ideas present in the architectural frameworks of the U.S. Department of Defense (DoDAF) and the British Ministry of Defence (MoDAF); [13-14]. These frameworks focus on the effective sharing of architectural "data" – rather than a focus on a product-centric architecture development process – to support decision making during development. Visualization of architectural data is accomplished through models with graphical representation thus facilitating communication and understanding among stakeholders. In particular, the DoDAF v2.0 defines Architecture development into a 6-step process. These frameworks are intended to guide the development of large systems, involving complex integration of many parts, and both generate development artifact models, called viewpoints, to meet the specific needs of the many business interests being represented. Each viewpoint represents a detailed description of the architecture from a different perspective. These views correspond to architecture Operational Capabilities.

At Atech, system components are called Operational Capabilities where each represents a self-contained implementation of a specific set of functionalities and analysis tools intended for operational use on a given domain application. As an example, in the ATC domain, the functionalities and analysis tools required for a thorough, efficient and effective air traffic control are realized by *Building Blocks*, which together make up or implement the ATC Operational Capability. The use of building blocks, inspired by the method presented in [15], is justified as a means to exploit reuse in system development, in compliance with IEEE 1517-2010 [4]. The use of building blocks for reuse becomes even more appealing when efficiency in large systems is a sought for requirement.

Perhaps the first thing that comes to mind when delving into the ATC domain is the picture of a large controller console with a myriad of visual elements crowding the display screen. This is implemented by the graphical geospatial reference interface along with accompanying support air traffic control functionalities. Another indispensable Building Block of this same domain is entrusted with the task of managing the position of flying aircraft, or flight tracks, on the control display screen. Additionally, alert managers, NOTAM managers, and controller issued objects manager are also present in the ATC Operational Capability. Notice, moreover, that systems in the ATC domain are essentially distributed systems where distributed computing is heavily employed and, thus, one important Building Block needed in the ATC system implements communication between nodes in a system network.

The application of the above processes has yield tangible benefits and software component reuse is already a present reality at Atech. The first system is a concept ATC system used to demonstrate specific functionalities with international partners. These functionalities included flight track, aeronautical, and boundary coordination sharing of information. It is estimated that as much as 30% of the development and implementation effort was saved because of software component reuse.

Two other systems were developed under the conceptual platform described above. The first system provides several types of information in order to increase situational awareness and improve the decision making process regarding the surveillance of the Brazilian coast. The main concept of this system is to present several types of information, including those provided by other external parties, in an integrated form. The adopted development framework allowed for parallelization of efforts naturally: different components were developed concomitantly and, therefore, the components integration to achieve the system was greatly simplified. The system presents contacts information, such as vessel and aircraft, on the HMI. Vessel information is acquired from system external tracking services. These services provide several information about a vessel, including position, speed, course, identification, timestamp of the detection, size, callsign and others. The HMI display the vessels' current positions, speed and courses, identification and a history of vessels position.

Vessels can be classified through HMI according to the military standards. This application was one of the first developed after introduction of the processes and benefited little from the reuse. It served, nevertheless, to pinpoint several potential components and interfaces to be re-used in subsequent development projects. The second application is a distributed system solution for tactical Command and Control missions. In the typical mission scenario, three types of land vehicles are used collaboratively. Each vehicle has a different objective and is, therefore, configured with a distinct set of system functionalities. They represent different system network nodes. As a result, the required data for each vehicle to carry out mission objectives is different since each type of vehicle employs a distinct system configuration. Vehicles' systems integration translates to publishing and reading subscribed data and presenting data on the HMI appropriately in a way that improves the decision making process. Situational awareness improves tactical decision making on the field. The system installed on the vehicles achieves this with information available from several sensors. This information is acquired by partners systems, i.e. systems outside the mission network, and the C2 system integrates data obtained from local sensors with those acquired from other systems and presents sensor information on a single user interface. Network data comprises GPS location data, video streaming, other sensor data, where each one is transmitted using different protocols. Approximately 40% of application development originated from the reuse of existing components.

An extra system development project also benefited from the processes described above for reuse. In-depth detail about this system development will not be presented here, sufficive to say that it is related to ATC and training operations. Development of the first version of this system achieved 40% of component reuse for the training module and 70% for the full ATC system implementation.

It is believed that greater measures of software reuse will be achieved as the components implementations or building blocks specifically, and process mature in time. Developer awareness about existing components also contributes; although this is not critical given CM tools indicate availability of components for development. Finally, appropriate project scope definition contributes significantly to reuse, given the influence of requirements specification on development and implementation phases.

5. Final Remarks

The subsystems and system elements of the simulation platform solution were developed following the practices recommended to support systematic software reuse. The communication issues were addressed through the creation of an architecture team responsible for making design decisions and detailed design of the software components. Without the support of the CM staff and the appropriate tools for version control, project configuration and artifact management the growing number of CIs would not be manageable. A key decision was the use of the NAR plugin to the Apache Maven tool, which allowed the smooth integration of *make* based build configuration of many legacy subsystems written in C language in an artifact management tool written to work with Java. This allowed for resolution of the overwhelming complexity related to platform architecture issues, as C compilations are not platform independent as Java byte code. Another important aspect of this work was the definition of an architectural style based on OMG's DDS. This decision was based mainly on the past experience on critical systems development at Atech. One desirable effect of the use of

DDS was the possibility of packaging the interface related code derived from IDL in compiled binary CIs, an approach that guarantees that two subsystems with the same version of the interface package in their configuration will be able to change information without problems. It is important to note that assumptions related to the data model and communication protocols may be encapsulated in the IDL and the overall data distribution mechanism is sufficiently generic to support an easy integration. The publisher/subscribe model also provides a solution with low coupling between the modules, imposing low dependency related to the flow control of processing. The effort related to the implementation of the reuse supporting tasks was due to the need of designing for reuse and the effort to maintain the design of system elements compatible with the architectural style defined for the project. The high modularity of the system, at first, presented a problem to the implementation activities, as modules were not available for use at the beginning, meaning that small developments were followed by quite complex steps to compile and publish new versions of the CIs. As the system evolved and some modules releases were available, the CIs management overhead became small, and the independence between modules and their versions was exploited and simplified the development process, mainly the building process, keeping explicit dependency relationship between modules in project model files. The documentation related to the binary assets with greater possibility of reuse is made available in an html site, and during this work, other development projects at Atech could make use of the newly deployed binary assets and their documentation.

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Interoperability and Visualization of Complex Products Based on JT Standard

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Abstract. With their response to the market and regulatory challenges, modern enterprises have introduced and continuously improved processes, methods and tools to feed the individual needs of their business domains, multidisciplinary teams and supply chain, mastering the growing complexity of virtual product development. As far as product data are concerned, data exchange, 3D visualization and communication are key processes for reusing manufacturing intelligence across lifecycle stages. User-friendly access to the increasing amount of information plays an essential role in business and leisure. Several CAD interoperability and visualization formats meanwhile have been developed to support product development strategies. Such activities also include national and international associations and standardization bodies. The emerged methods and systems aim to increase the performance, acceptance, and user experience of graphical data representations for a broad range of users. This paper analyses methods and tools used in virtual product development to leverage 3D CAD data in the entire life cycle. It presents a set of versatile concepts for mastering exchange, aware and unaware visualization and collaboration from single technical packages fit purposely for various domains and disciplines.

Keywords. 3D, Visualization, Collaboration, Exchange, JT, STEP, PDF

Introduction

The gradual cyberization of physical products and predominantly the introduction of Computer Aided Systems have triggered a digital transformation movement in Manufacturing. Applying 3D CAD and PLM strategies has fundamentally led to higher productivity, better quality and a simultaneous reduction of overall development time and costs [1].

Meanwhile, product development methods such as Concurrent Design, Simultaneous Engineering and Systems Enginnering have widely been adopted [2]. They tend to manage complex development tasks in such a way that independent units can be processed concurrently to build an optimal technical solution designed for a complex issue. They ensure inherent behavior of each unit as well as system-wide interactions according to weighted objectives [3] [4].

The principle advantages provided with above-mentioned methods and tools have likewise contributed to growing complexity. Combined with various domain- and organization-specific software applications available with new product development trends, the pace of changes, the amount of data and the quantity of knowledge inserted in virtual product data are now reaching exponential growth [5] [6] [7].

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Attaining better performance and accuracy while providing product data to the right party in the context of his current application is essential for greater time-to-market. As de-facto reference of the physical product, from which downstream data are derived, the 3D product representation deserves a particular interoperability attention [8]. Modern organizations thus invest in activities required to achieve seamless experience with 3D data across applications, disciplins and supply chains [9]. These main activities are: the exchange of product relevant data across aforementioned layers; the visualization of cyberized products with purposely disclosure of source intents and the communication [10][11][12].

Mastering quality, product design and configurations, bill of materials, changes and releases requires an overall product and process integration, which takes care of differences in coordination workflows [13], engineering domains, methods and tools of the different parties participating at product life, while safegarding all current investments (Figure 1) [14][15][16].

The paper is organized as follows. In section 1, the business challenges in interoperability and visualization are briefly described. Section 2 discusses in more detail the current approaches for 3D-based collaboration. Deployment of JT and practical experiences is highlighted in section 3. Section 4 contains a summary and ideas for further research.

1. Business challenges in interoperability and visualization

In the past several interoperability data formats arose. There are basically two primary types of formats: proprietary and open formats.

Proprietary formats are vendor-specific. They are used to describe product data in the majority of authoring tools in the marketplace. Descriptions of these formats are generally regarded as intellectual property by the software vendors and are suitably protected. Due to their lack of openness they are essentially less appropriate for collaboration in the extended enterprise. They will no longer be considerered in the context of this paper.

		Viewing				Viewing + PMI							Viewing + PMI + Kinematics								
Product Lifecycle Phases	Generic processes	Viewing	Bidding and Inquiry	Material specification	Packaging	Drawingless manufacturing	Supplier Integration (OEM2SUppl.)	Finite Element Analysis	Dife: Factory DMU	Dife: Factory building planning	Dife: Plant Development	Tolerance studies	High-end Visualization	Dife: Material handling	Dife: Manufacturing planning	Supplier integration (Suppl.2OEM)	Non-hybrid design in context	Installation Feasibility	Multi Body Simulation (MBS)	Hybrid design in context	Archiving
1 Acquisition	Bidding and Inquiry	×	×	×	×	×	×	×	×	×						×					
2 Enigneering (Product Development)	DMU	×		×	×	×	×		×	×	×	×	×			×		×			×
	Design in context	×	×	×	×	×	×		×	×	×					×	×			×	
	Simulation	×		×		×	×	×			×	×		×	×	×		×	×		×
	Digital factory processes	×		×		×	×		×	×	×			×	×	×					
4 Production	Production-Planning + -Control	×		×		×															
	Manufacturing+ Assembly	×		×		×															
	Logistics	×				×															
5 Sales	Marketing material	×		×									×								
6 AfterSales	User manuals	×																			
	Repair instructions	×		×		×												×			

Figure 1. Potential application of 3D formats during product lifecycle.

On the other hand open formats are often designed to enable interoperability between applications. They provide descriptions which are openly specified and accessible to third-parties (application vendors and customers), who wish to make data available from and to their own applications. Open formats and particularly standards ratified by a recognized international organization are stable by nature and may slowly evolve [17]. Open standards however, enable the reduction of total cost of ownership and ensure independence from specific vendors by making sure that the data they encapsulate is always capable of being leveraged downstream and recoverable from an archive repository [18].

It hereby goes without saying that formats such as IGES, DXF, STEP, 3D XML or JT are being widely accepted and have helped to improve dynamics in product development [19][20].

IGES defines a vendor-neutral file format by information structures for the digital representation and exchange of information like product definition data. It supports exchange of geometric, topological, and non-geometric product data beneath CAD/CAM systems such as: administrative identifications, design or analysis idealized models, shapes, processing and presentation information. It is used for applications such as traditional engineering drawings and design as well as models for simulation analysis.

The development of STEP started in 1984 as a worldwide collaboration. The initial plan was to define a mechanism that is capable of describing product data throughout the lifecycle of a product, independent from any particular system. This type of attempt was made for the very first time. By nature of its specification STEP is suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

Typically STEP can be used to exchange data between CAD (computer-aided design, CAM (computer-aided manufacturing), CAE (computer-aided engineering), PDM (product data management)/EDM (engineering data management) and other CAx systems. STEP appeals product data from mechanical and electrical design, geometric dimensions and tolerances, analysis and manufacturing, with additional information specific to various industries such as automotive, aerospace, building construction [21], ship building [22], oil and gas, process plants and others. Unlike modern formats like e.g. JT, STEP has not the option "lightweight" representations of a product or object, nor does it concern itself with compression. This makes STEP not first choice for visualization in downstream processes.

STEP is the most important and largest effort ever established in the engineering domain and has replaced various CAD exchange that were used prior to the widespread industrial acceptance of STEP. It is developed and maintained by the ISO technical committee TC 184.

The JT format described in ISO 14306:2012 is used mainly in industrial use cases as the means for capturing and repurposing lightweight 3D product definition data [20]. The development of the binary file format JT started in 1990. It is used as both a data exchange format between design partners and manufacturers, as well as for visualization applications such as digital preassembly (also called digital mock-up or DMU) [23] and generalized visualization, more commonly referred to as view/measure/mark-up (VMM).

Due to its container structure JT shows "duality": it is able to be used in cases where data exchange from one application to a second, as well as in cases where visualization is desired.

JT is actively used with fast rising trend. As of today several millions of JT files are managed in automotive PDM systems alone covering a multitude of engineering use cases. It has emerged to a major 3D format in automotive collaboration, which requires a particular interoperability focus to maintain the stringent process and quality requirements of its different applications [24].

As a matter of fact, among all the aforementioned proprietary and open formats, none delivers overall versatility and capabilities by its own to equally sustain the varied demands of collaboration [25] in the extended enterprise and further, beyond product development stages of product lifecycle (Figure 2). Either they are not easily accessible or they do not have sufficient capacity for sharing dissimilar representations of same product (e.g. 2D/3D CAD, CAM, BoM, etc) across different applications, domains and teams. Or they aren't providing sufficient tools and SDKs to support and adapt the collaboration experience. Or their industrial use is very low or they just are not ratified by a recognized standards body, which makes them strategically unsustainable for modern organizations.

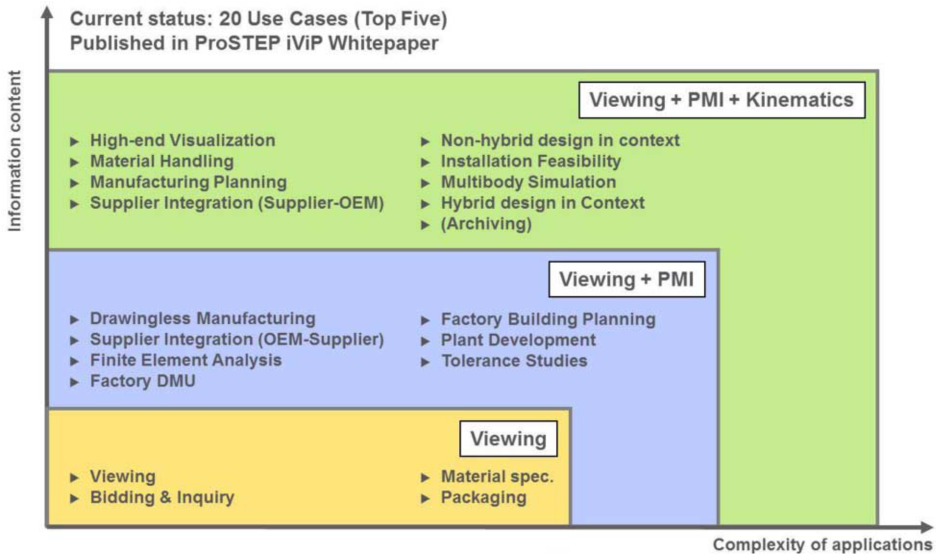

Figure 2. Schematics for Use Case Structure.

The industrial application of these 3D formats have moreover been around the transport of specific data sets mainly for the purpose of visualization, data exchange or bulk migration (Figure 2) in downstream processes, whose underlying goals are presentation and transformation of native 3D CAD geometry from an authoring application into an alternative format. The resulting data is finally translated into a proprietary format of a third party application for use in e.g. design, validation, and viewing or long term archiving.

Normally and as far as engineering collaboration is concerned, different parts describing an affected request and their virtual product data are delivered through diverse channels and towards quite a lot of authoring systems; be it a request for information, work, change or approval. E-mail, CAD and various data exchange applications as well as a bunch of data communication channels are also used [26].

Basically, this approach is a limitation to leveraging product data across lifecycle stages, domains and supply chains, because the necessary information is supplied in disconnected parcels. They have to be collected systematically, and re-aligned to each other on reception to effectively consume them. In many cases, they have to be translated into the workspace of the receiver. The missing link between these parcels, though, is an issue that leads for many organizations to unnecessary bureaucracy. As far as manufacturing is concerned, this means that the development partners must support several systems and configurations and are additionally busy adapting and integrating data instead of using them right away.

2. Current approaches for 3D-based collaboration

Lifecycle Collaboration should be more versatile than providing chunks of data [27]. It is more than disconnected product structure, visualization or 3D design! It is the logical combination of all relevant data flows put in context with a recipient consuming these data to better perform a set of product development tasks. Under this consideration, research and industrial communities are investigating approaches incorporating different types of information [25].

Pushing the practical penetration of JT in engineering downstream has enormous potential for manufacturing. Regarding this, there is one effort – the first of its kind – aiming at the smart combination of the two international standards STEP and JT to establish a process oriented solution for supporting automotive data exchange requirements, which incorporates not only 3D visualization but also process relevant capabilities. The manufacturing community has recognized that JT itself can only reach its full potential by applying it in combination with smart XML functionalities of the Application Protocol (AP) 242 of the STEP standard [24]. In this perspective, STEP AP 242 should become the process backbone for e.g. assembly, metadata and kinetic, whereas JT is enabler for lightweight visualization of 3D data.

Detailed information hereto can be found within the JT Workflow Forum (JT-WF) [28], a joint project group established by the ProSTEP iViP Association and the VDA (German Association of the Automotive Industry) in 2005. The objective of the forum is to drive the requirements relating to the application of JT and the accompanying format STEP AP242 XML, to validate them, to document the processes in use cases and to harmonize the necessary characteristic of the used JT as well STEP AP242 XML data content. JT Workflow Forum has already described 32 use cases for implementation [28]. One of the most important drivers for future development and deployment of JT is Daimler, where JT is the central resource for provision of 3D data (Figure 3).

The advantages provided with JT however do not have a life cycle coverage yet. Still today, most organizations are seeking for concepts and best practices in reusing their product data not only in product engineering but e.g. also in facility, product planning and manufacturing execution, where STEP and other formats for instance are already applicable. This situation is enforced with lack of standards for data exchange and interfaces between cross-domain systems used there, which are fundamental for collaboration with external partners in production (digital manufacturing).

The lack of direct support for JT causes for instance requests for translation to perform machining operations.

The recommendation 4953-2 is an implementation proposal of the German Automotive Association (VDA), which describes concepts and means to replace the conventional 2D drawing (as a leading carrier of product information) by documentations on the basis of a technical data container [29]. The scope of this recommendation is a document-based container, which includes mandatory and optional contents with 3D data streams and their linked technical metadata. The aim is to eliminate the need existing in many areas of derivation and management of 2D-based collaboration and technical documentation.

This guideline describes the structure and management of product data embedded in a technical container as well as its architecture. A 3D content with annotated geometry representation is one of the main compulsory content having attached JT (ISO 14306) files as recommended 3D carrier. A structured metadata content, which isn't embedded into but linked with the 3D content, is building a second mandatory part of the proposal. VDA 4953-2 recommends STEP AP242 BO XML-Format (ISO 10303-242) for storing metadata and PDF/A (ISO 19005) for presentation inside the container. Optional contents can be embedded and should be of any file format that can be used for long-term archiving.

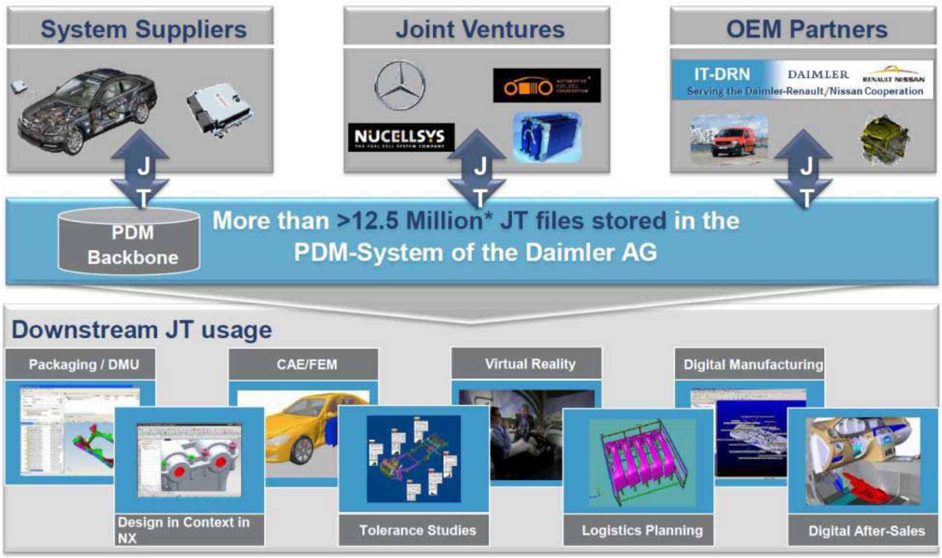

Figure 3. Scenarios and processes for JT deployment at Daimler.

Based on a similar concept, a further German automotive OEM Volkswagen has published and presented such a container using PDF as container and JT for storing 3D product data. An external viewer is launched interactively to present and query 3D JT objects such as PMI and technical descriptions from the PDF/A presentation layer. Meanwhile, it is used as a basic tool for various internal downstream processes.

One development approach alongside PLM, which declares the 3D CAD model as the record of authority and the source for which all other documentation flows is Model-Based-Design (MBD). By emphasizing digital CAD file use for collaboration at the beginning of development, it is the ground for a fully integrated and collaborative environment founded on a 3D model based definition detailed, documented and shared across the enterprise to enable rapid, seamless, and affordable deployment of products from concept to disposal [30]. Thus, Model-Based Definition (MBD) is a concept of managing engineering and manufacturing information using 3D models as primary source and record of authority of all other product data related to design, process planning, manufacturing, test, services and overall product lifecycle [18] [31]. MBE in its core is truly not pushing a format or a tool [32]. It is rather defining a "3D Master" with its associated descriptions and technical files to push interoperability one step further. It thus can be implemented with various standard formats such as STEP, JT or PDF.

These particular interoperability formats are selected by various manufacturing organizations to achieve the vision of a Model Based Enterprise at numerous levels: which basically is reducing the significant manual intervention in the supply chain to go from product design through product lifecycle downstream such as manufacturing or quality inspection.

Despite the industry MBE vision to become model-centric, 2D drawings is still playing a fundamental role for technical documentation between OEMs and their suppliers. Many among them still exchange design data in the form of full-annotated-2D drawings combined with 3D-shape-geometry model. Only a small percentage of the manufacturing actors use just a 3D model with embedded 3D-PMI partly due to following barriers [33]:

- 2D Drawing is still considered the master versus the 3D Model by many in industry.
- There is a significant learning curve to effectively embed PMI into a 3D CAD.
- There is an overall supply chain work to consider before adopting 3D PMI in the development process.
- Many application program interfaces (API's) do not adequately support downstream processes due to lack of PMI.

VDA recommendation 4953-2 in chapter [29] is an instantiation of the model-based design principles.

3. Deployment of JT and practical experiences

In the past few years JT was widely adopted by many global enterprises, in particular in the automotive industry. They have built a JT-based infrastructure which allows that each authorized user can access the JT data during the product lifecycle. Large enterprises report on successful implementation and deployment [34]. Among others, JT is primarily used in the following downstream processes: Design in Context, Data analysis, Multi-CAD, High-end visualization, Supplier Integration, Geometrical search, Assembly validation/DMU, Archiving.

In combination with STEP AP242 XML, JT has become a powerful means for support of many engineering tasks, as reported from interviewed users (Figure 4) [28].

Users are unanimous in their assumption that approximately 30 percent of the costs currently incurred for CAD licenses can be saved permanently as the result of introducing the neutral standard format. This is especially true for companies who are forced, for various reasons, to implement a number of different CAD systems. Some of these implementations may then no longer be needed, provided the exchange of data with partners and customers for certain purposes can be changed over entirely to JT.

Data exchange between native formats often results in the need for reconditioning to correct any transfer errors. Once an agreement regarding the use of JT has been reached, the number of transfers required between native formats will be subject to a significant decrease. This means that the amount of work currently required for reconditioning the data from internal and external partners will also decrease markedly.

The smaller size of the JT files and the simple, often automatic, conversion make it much easier and at the same time faster to exchange data between different CAD systems, for instance for design in context. However, the size of the JT file heavily depends on its configuration.

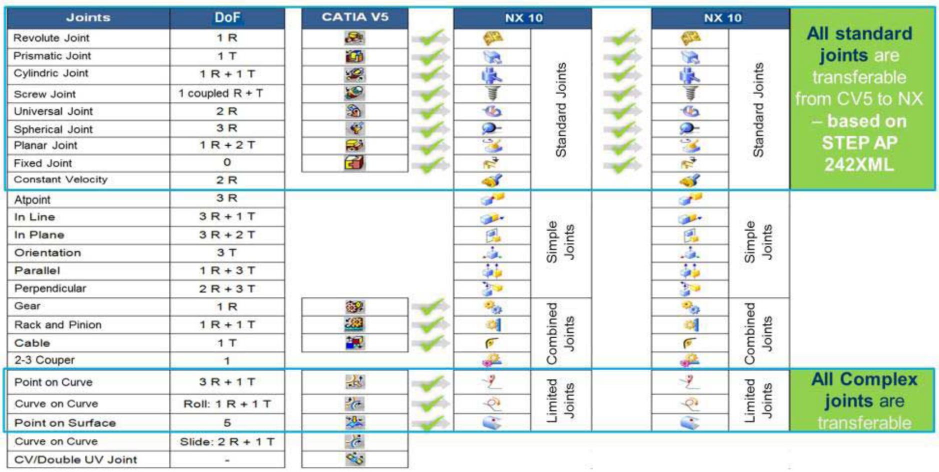

Figure 4. Exchange of kinematics data via STEP AP242 XML.

All those involved expect the processes that can be supported in the future as a result of the availability of JT to improve dramatically and, above all, be easier to use. The ability to rely on not words but visual support across departmental borders, in non-technical process and via the Internet will release a considerable amount of energy that was previously inevitably required to search for data, explain documents and disseminate information. In the same way that NetMeeting supports telephone and video conferences and 3D-PDF allows the creation and processing of a wide variety of documents, so can JT become a core element in collaboration scenarios that involve engineering data.

4. Conclusions and outlook

This contribution has addressed the state of the art activities for establishing JT as universal process format for interoperability and visualization of complex products. 3D interoperability is an important contribution to engineering collaboration. Several formats made to for this purpose successively deal with challenges of their time. Some of these such as STEP are very detailed formats, which gradually encapsulate all information necessary to define a product, its manufacture, and lifecycle support. Others focus mainly on lightweight visualization use cases and endure better with increasing size and complexity of data. The status of JT is very promising. Its application has reached high level of maturity with a eco-system consisting of developers, adopters and users. However, in the era of lean and agile, seamless collaboration needs continuous planning [35].

There are further requirements for 3D formats for the visualization and downstream processes, and complementary formats in order to exchange meta-data, structure data and kinematics data as well as open and standardized formats to reduce total cost of ownership and to minimize dependency of single vendors. As shown in Figure 5, the exemplary scenario for exchange of product structure, geometry and meta-data expresses that the data exchange based on JT and STEP AP242 XML is possible with few weak points (translation and proper interpretation of attributes).

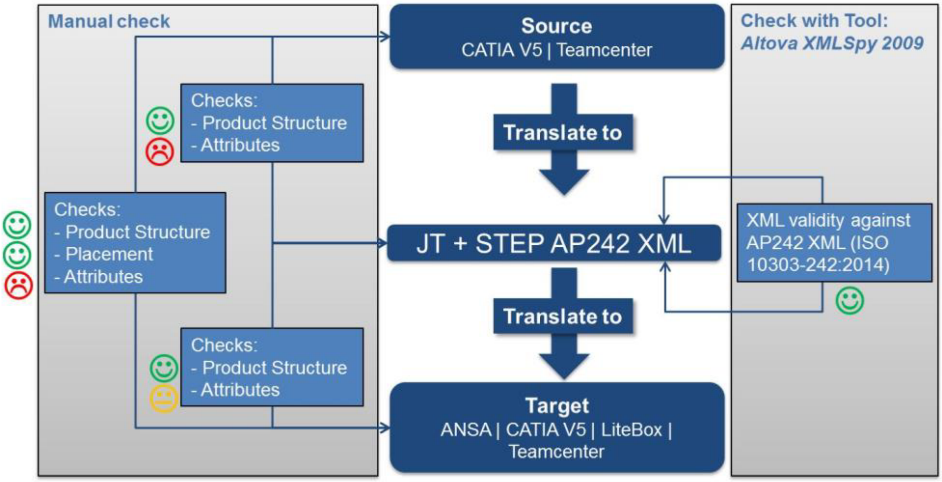

Figure 5. Data exchange scenario with JT and STEP AP242 XML.

Further implementation and integration of remaining use cases with the accompanying format STEP AP242 is the major forthcoming task for JT development. In version 2.0 JT will adopt further representations of geometry model. Further development is preserved by international bodies which include implementer fora.

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Part 13

Service Engineering

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Modifying Maintenance Practices Within a Maritime Support Solution — A Cultural Perspective

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Abstract. Maintenance culture is a critical factor in sea power delivery and is embedded throughout all aspects of the maritime support solution. Preliminary research suggests that Royal Australian Navy (RAN) maintenance staff and civilian support organisations do not hold positive attitudes towards asset management. As a result, there is evidence that maintenance culture should be defined and improved. However there are no adequate instruments available to measure this gap in culture and attitude within the RAN, or their associated support organisations. Hence the intent of this research is to validate the theory of a poor maintenance culture across all facets of the RAN ship maintenance support solution. Maintenance culture has for too long been about maintaining ships rather than maintaining ship's reliability (also known as conducting maintenance for the sake of conducting maintenance). This paper investigates asset maintenance support solutions leveraging experience from alternative industry to augment the culture towards maintaining naval assets.

Keywords. Maintenance support, Navy ships, change and cultural aspects

Introduction

Reduced manpower in the Royal Australian Navy (RAN) has resulted in the focus of technical sailors shifting from maintaining naval assets to operating them. This reduction in manpower, when coupled with a largely unchanged maintenance philosophy, is affecting the maintenance culture across the fleet and has impacted asset reliability and availability. This paper investigates some of the causes for this cultural decline.

"We have for far too long viewed engineering as an overhead and not as a mission enabler" Vice Admiral Ray Griggs — Head of Naval Engineering [34].

Historically, governments attempted to achieve social and cultural change through interventions, including fiscal incentives, legislation and regulation, and information provision [17]. A prime example of culture change through legislation is the nation's change in attitude towards drinking and driving and the wearing of seatbelts. It is expected that with the RAN's improvement in its technical regulations over time the

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maintenance culture will mould itself to support them, provided leadership views it with priority. Rizzo, O'Keefe and Charles-Jones recognised the manpower levels within the RAN are impacting the ability to conduct maintenance on board RAN ships [7][25]. This reduction in numbers has resulted in a practise called ‘minimum manning’ which requires technical staff to amalgamate roles and become both system operators and maintainers. The line between operator and maintainer has become blurred. This has resulted in reduced technical integrity as sailors spend greater time achieving operator qualifications, participating in compulsory ship duties and reduced time conducting planned maintenance activities [25]. Maintenance programs fail to take full advantage of modern optimised maintenance practices when developing planned maintenance systems for new ships, instead relying on Original Equipment Manufacturers (OEM) recommendations and confirming their suitability for on board use or modifying slightly to accommodate bespoke installation constraints. While the RAN harbours desire towards increased asset management, the reduction in technical sailors and reliance on existing planned maintenance systems hinders its progress. Rizzo identified further critical failures centred on the maintenance culture exhibited by the RAN, further complicating the effective maintenance of Defence materiel [25]. This maintenance culture failure can also be applied to organisations supporting the RAN and ship’s staff.

Matsumoto has been widely quoted defining culture as “...the set of attitudes, values, beliefs and behaviours shared by a group of people, but different for each individual, communicated from one generation to the next” [20]. Hofstede adds weight to this by defining culture as “the collective programming of the mind distinguishing the members of one group or category of people from another” [16]. This implies that people are a product of their environment, which has been accepted for some time now. To break this down even further there are some common elements in these two quotes. Matsumoto uses the term “shared”, while Hofstede uses “collective”. Both of these state that values are felt throughout the group, and as a consequence you need to modify the “…attitudes, values, beliefs and behaviours…” or “…the collective programing of the mind…” and any change must be accepted by every person within the group. Matsumoto further states these values are communicated through generations implying they have been proven or validated previously so why would change be required? Should a new individual become part of the aforementioned group, it is natural that they become indoctrinated in the ways of the group developed over time. Should an individual attempt a change that conflicts with these proven values it would be a very difficult task [33]. In addition differing sub-cultures may exist, for example within individual trade groups inside the larger ship’s organisation. Whilst these sub-cultures exist to adapt to problems specific to their trade or work area, the core culture will always reflect that of the larger organisation.

Any change that conflicts with an organisation’s culture will be extremely difficult to introduce. However new values and beliefs can be developed through good company policy, operational practices and a management style that can become culture in the future [32]. Considerable research has been carried out into culture and asset management and its effect on asset reliability within commercial organisations. However, the Defence Forces are vastly different to commercial organisations.

1. Government reviews

Rizzo identified a culture that exists within the RAN that placed a higher priority on short-term operational missions than technical integrity [25]. New Defence projects, such as the Landing Helicopter Dock, Air Warfare Destroyer and, while not a true Defence project, the Pacific Patrol Boat Replacement, require a maintenance program incorporated within the Support Solution. Rizzo further discovered the degraded state of the Amphibious and Afloat Support Ships could be largely attributed to neglected maintenance and confirmed the presence of a culture where RAN operators did not view maintenance as an enabler of operations. Conversely however is the fact that since the 1980s the Australian Government have been actively encouraging Defence to reduce expenditure effectively diluting in-house technical expertise and outsourcing technical capacity [28]. Gan echoes this sentiment but further elaborates stating that outsourcing is allowing corporations to focus on the core business [11]. While budget reductions and outsourcing is a sign of the times, the way in which they are handled impacts the maintainer of naval assets. Any outsourcing requires careful planning and communication to prevent a mistaken belief that it is another form of privatisation [30].

Woodhouse states that departmental silos and conflicting priorities need to be broken down to realise value [37]. Removing silos (having the same standards across fleet) and de-conflicting priorities (Commanding Officer and Engineering need to improve communication) requires a considerable change to the culture and leadership within an organisation. The concern is priorities are often dictated within military organisations. Woodhouse continues to state that many organisations often chase greater efficiency, sometimes to the extent of doing the wrong things that appear faster, cheaper or better. Belnap discusses the repair by replace practice on board the ANZAC Frigates [2]. While repair by replace has reduced planned maintenance it has instilled a run-to-failure approach, interpreted by some maintainers that a disposable asset equals a disposable resource. If a maintainer is not going to repair an asset then why have them at that higher skill level when the required skill can be outsourced to private enterprise? This results in a further negative cultural shift. While it is easy to comment on the current state of maritime maintenance culture, as compared to an organisation with a proactive culture, it is difficult to make broad recommendations to modify the existing culture as maintainers on board ships constantly find themselves in ever changing environments [21].

The Black Review dedicated a section to the culture surrounding general accountability within the Defence Force [3]. It highlighted the existence of a traditional, excessively rules based culture and an organisation that values process over outcomes. While this review identified numerous issues with the culture in the Defence Force, albeit with an accountability bias, it failed to offer some real recommendations on how to correct the shortfall.

The First Principles Review recommended that Defence personnel only be used in roles that cannot be fulfilled by a civilian counterpart [23]. It further recommended that as many functions as possible be outsourced if they are only transactional in nature, for example System Program Offices (SPO). While SPOs provide tangible value, the bulk of their workload is transacting outsourced tasks with the relevant service and overseeing task legislation and governance. This means that support organisations will eventually take a greater role in dealing with each service. This is not without complications as civilians dealing with defence personnel, and vice versa, can be fraught with misunderstanding.

2. Outsourcing Maintenance

While outsourcing asset maintenance allows sailors the ability to concentrate on the core task of war fighting, the perceived perception that Defence Forces can “do away” with the core aspects of asset maintenance appears to be further driving adverse culture and a resistance towards change. The outsourcing of maintenance was intended to unburden the sailor while ships were alongside, however this practice has morphed into more of a solution for difficult maintenance tasks or those tasks of a more menial nature. Ng and Nudurupati argue that the RAN, as customers of service contracts, are more interested in haing a stable fulfilment of their needs rather than owning the maintenance burden itself, based around having a serviceable ship that can conduct the operations requested of it when required, ie. customers are actually buying a hole when they purchase an electric drill and not the drill itself [22]. In ship maintenance, a positive culture is necessary to underpin and support ship reliability through the conduct of effective maintenance ultimately leading to a ship that is ready for all requested operations. Organisations offering product service systems that are in receipt of this outsourced maintenance must therefore focus on selling satisfaction to the RAN through demonstrating effective maintenance underpinned by a positive maintenance culture rather than the product of maintenance on its own [19].
Woodhouse mentions that resistance to change could be part of a perceived clash of priorities derived from misunderstandings or subjective interpretations of priorities [37]. Further complicating outsourcing is the fact that the RAN is steeped in tradition and takes pride in their honours, beliefs and ideals [4][30]. The outsourcing of a sailor’s job, even minor aspects of it, is counter to these aforementioned traditions.

While the outsourcing of asset maintenance appears to be here to stay due to minimum manning, both Gan and Swarts agree that it requires significant effort on the contractor’s behalf [11][31]. Gan goes on to say that one of the many operational drawbacks involved with outsourcing is a lack of ownership of the asset as the contractor is required to “repair as required in plan”. This philosophy ultimately leaves the asset owner (and original maintainer) little incentive to monitor the asset as an operator, leaving them oblivious to the possibility that the root cause of failure could have been avoided by remaining accountable for the asset in question.

Research has also been conducted into the disadvantages of global Defence Forces outsourcing with Suman stating that it tends to become an irreversible process and dependence on service providers becomes permanent. Greco alludes to outsourcing adding value to those tasks that are not core to the organisation [12]. While generic maintenance is core to the RAN, specialist skills like non-destructive testing or maintenance analysis would not. While there are obvious benefits to both side of the outsourcing argument, the RAN find themselves in an awkward situation. Suman states that modern wars are technology intensive and maintenance of these systems requires extensive resource commitment that could be best outsourced, as in-house competence would never match the experience of the equipment manufacturer [30]. However, the problem occurs however when equipment fails in theatre and there are no experts trained in the repair, nor would there be any spares on board. While the RAN has proven itself to demonstrate a win at all costs, can-do attitude, this can lead to potentially dangerous scenarios such as maintenance being performed without adequate experience or training in order to complete operational missions [29].

3. Total Productive Maintenance

The introduction of newer technology into maintenance regimes require the RAN, and support organisations, to more effectively manage the life cycle of their physical assets. According to the Asset Management Council of Australia, this is essentially the definition of asset management. Total Productive Maintenance (TPM) is fundamental to to a successful asset management program [36]. TPM is supported by five basic pillars:

1. Improve equipment effectiveness by targeting major losses.
2. Autonomous maintenance or involving operators in maintenance.
3. Improving effectiveness and efficiency of maintenance.
4. Training.
5. Manage equipment early, including preventative maintenance design.

These pillars can either be augmented or degraded depending on the culture towards maintenance exhibited by an organisation [14]. A key detractor to achieving TPM on board a ship is a disconnected leadership. While the upper levels of the organisation commits to modifying practices, it is the existing culture and habits that ultimately decide the proposals effectivity. A key aspect of TPM is to change the traditional approach of “I operate, you fix” to a “prevention at the source” style [9]. This drives the need to investigate whether maritime maintainers consider themselves to be operators, maintainers, or a combination of both. Converse to this change is aviation where operators and maintainers are two separate and distinct trade groups, yet aviation has a proven positive maintenance culture. The benefit in having operator/maintainer status is a greater sense of ownership if the asset is being operated and maintained by the same person.

RAN maintainers have indicated they had noted the shift towards becoming both an operator and maintainer, however had not realised the full potential of this combination. This is likely due to the outsourcing of maintenance and transient nature of service life.

4. Human Factors in Maintenance

Changing Human Factors within maritime industry have historically evolved as a result of accidents, despite the International Maritime Organisation (IMO) stating it has a proactive approach to managing Human Factors [27]. The emphasis placed on Human Factors surrounding maintenance in maritime industries has been viewed differently to those in adjacent industries, such as aviation, mining or power generation, due to differing consequences of failure. There are two key objectives to Human Factors when it is applied to man-machine systems [6]:

1. Human Factors affecting operators and users are used to improve work environments; aesthetic appearance; ease of use; and reducing fatigue, boredom and monotony.
2. Human Factors affecting reliability and maintainability are used to improve reliability and maintainability, while reducing manpower requirements and training.

The IMO mandates ships living and workspace design standards as well as work-rest requirements. However, the master of the vessel has the right to suspend these minimum requirements and ensure any work necessary to protect the immediate safety of the ship and those onboard (IMO/ILO). Hetherington, Flin and Mearns observed officers and seafarers reporting increased levels of stress and fatigue [15]. Furthermore, it was noted that 66% felt that extra manning was necessary to reduce fatigue and 70% of Australian seafarers reported "poor" to "very poor" sleep. While these studies focused on civilian seafarers, it is suspected this would be similar to RAN maintainers.

While objective 2 discusses the reduction of training, rather the approach to training should be modified. Sani states that training should not be limited to the transfer of technical skills and knowledge, but should be an ongoing process that improves the maintainer's skills and knowledge to augment maintenance practices and thereby the associated culture supporting these practices [26]. Occupational stresses on board RAN ships are likely to a certain extent and will generally fall into four categories [8]. These are:

1. Workload-related Stressors are either work under-load or work overload. Under-load is typically those jobs of a repetitive or boring nature. Work overload will usually exceed the skills and training of the maintainer.
2. Occupational change-related stressors involve cognitive and behavioural factors in maintainers.
3. Occupational frustration-related stressors are derived from poor communication, poor career development or role ambiguity.
4. Miscellaneous stressors are environmental type factors such as lighting, temperature and noise.

Human functional performance is related to the level of stress, as shown in Figure 1.

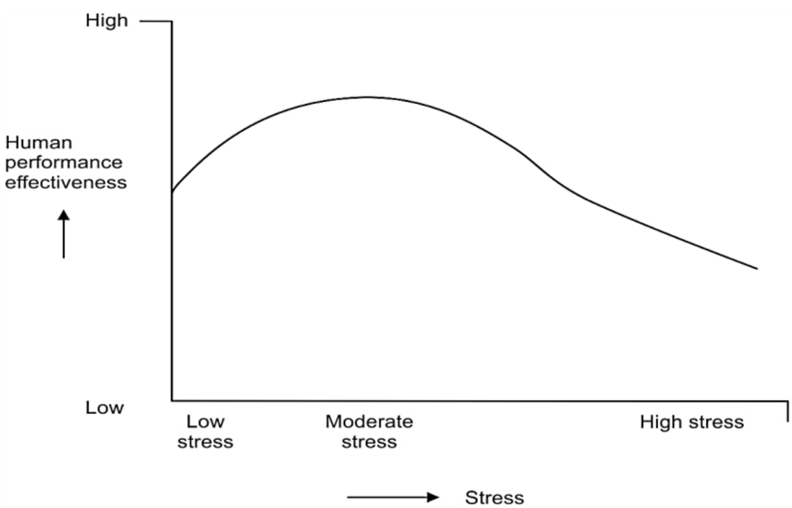

Figure 1: Performance vs Stress.

While a moderate level of stress shows an increase in performance, the definition of moderate is subjective and will vary between individuals. Research has shown that workload is negatively related to job satisfaction and positively related to depression, anxiety and irritation, all stress precursors [5]. It is likely that maintenance will not be carried out or the quality of maintenance will suffer should maintainers become increasingly stressed.

5. Commercial Insight

When compared to commercial industry, Defence Force assets are generally more complex than commercial equivalents [13]. Complexity is further increased due to operational environment: from freezing Antarctic waters to warm tropical waters. While there is a greater use of Commercial-off-the-Shelf (COTS) components and systems in RAN ships, complexity increases when interfaced with other on-board systems. Ng and Nudurupati state that higher availability and readiness of assets demands a more pro-active approach to maintenance from organisations engaged in outcome based contracts [22]. Commercial support organisations often employ ex-Defence members as they have normally finished their service contracts at a relatively young age [30]. While it makes good commercial sense to tap into this valuable resource, it is likely that any poor maintenance culture ideals will be transferred. This is not a severe problem as a new proactive group or support organisation has the ability to correct any undesirable habits relatively early on as new workers fit in with their new surroundings.

Nuclear power plants in Northern Europe have had similar reorganisations as experienced within the RAN (downsizing and outsourcing). Research into these changes noted a strong ambivalence towards organisational change and changes to the working environment [24]. Maintainers identified the required changes in the workspace but had perceived their specific role was incapable of change. This echoes the RANs experiences with its strong traditional values and perceived negativity towards outsourcing. Newer technology within nuclear power generation forced some old habits to be unlearned, but the longer the habit had been in use, the harder the change. This was validated by instructors of RAN maintainers who noticed that new sailors or those from ships with newer technology adapted quicker to new RAN platforms. Sailors from older ships were more likely to follow how business was done on their past ships. Reiman noted that anticipation, emphasis on certainty and cultural stability were all central features of a high reliability organisation and any changes to these principles were considered demanding or stressful and likely resisted [24].

Everyone within an aviation organisation shares the common goal of safe air travel. Aircraft maintenance is a critical link to achieving this proactive safety culture and is a dynamic, highly regulated, safety critical and complex industry, often regulated by legally binding procedures and documentation. Similar to the RAN, designers and maintainers face unprecedented challenges from customers to increase their reliability [35]. While facing these challenges, safety remains paramount. A consequence was the development of a reporting culture that is accepting of good news as well as bad without fear of punishment.

Advances in technology in the mining sector have enabled physical tasks to be conducted remotely [1]. Remoteness normally associated with mining usually prohibits having specialists on hand "just in case" there is equipment failure. With the RAN having moved into maintainers performing more operator roles and outsourcing technical tasks this solution carries some merit as it would give the maintainer access to specialist tradesman from OEMs without having to have all maintainers trained to deeper levels than required. Remote guidance when coupled with an automated data reporting system like eMaintenance, would provide a complete maintenance support solution to the RAN and would likely reduce the ships Total Cost of Ownership (TCO) over its life. By involving the sailor in these activities it is likely that any negative impact to the current maintenance culture will be mitigated. In fact, it is highly possible that maintenance culture will be enhanced as the types of jobs requiring remote guidance are likely to be complex and challenging in nature and the sailors are effectively receiving one-on-one expert tuition by the OEM on a system that they have previously operated.

6. Managing Culture

Acquisition or upgrade projects or upgrade that entail capital improvements impact the maintainer. Whether through new roles, greater outsourcing or other means, the cultural component is often forgotten or taken for granted and the maintainer is expected to adapt and get on with the tasks at hand [36]. In order for a change to occur, Thomas lists three elements that are needed [33]:

1. A vision for the future.
2. The steps required to achieve the vision.
3. Dissatisfaction with the current state.

Point 3 adds the incentive to overcome resistance to change. An obvious dissatisfaction is a feeling of not having enough time to complete assigned daily tasks. Even with dissatisfaction, any change would still prove difficult due to the RAN being steeped in tradition and wary of change [4]. Thomas highlights there are normally four organisational cultural modes with the RAN fitting into the “Show Me” quadrant due to being a highly motivated group that is very traditional and wary of change. “Steeped in tradition” and “wary of change” are phases that are further echoed by Woodhouse who uses “consistency and the comfort of the familiar”. It is for these reasons that any attempt to modify the existing culture should be made cautiously and embraced to ensure changes are fully adopted and become the normal way of doing business. Without this support it is likely that any proposed changed will be viewed as the latest fad or the “flavour of the month” [10].

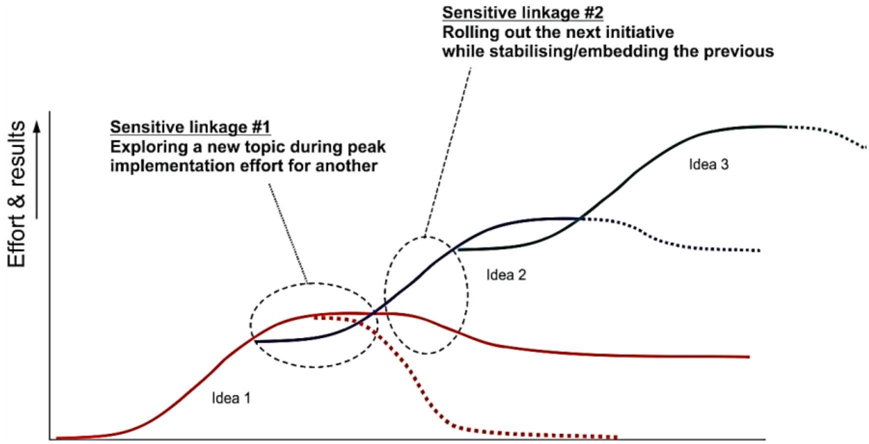

Figure 2: Enthusiasm-decay cycle (Woodhouse 2004).

This can be represented by Woodhouse’s enthusiasm-decay cycle, shown in Figure 2. A new way of doing business or modifying culture (Idea 1) will gain traction as participants start to see initial results and build confidence. Without leadership commitment, this change will inevitably trend back to where it once was. With continued guidance and support, any change will still trend slightly towards how it was pre-change, however this will plateau at a medium which will become the future normal and the new way business is done. When an organisation identifies areas for improvement, the point at which to introduce the next change must be treated with caution and is highlighted in Figure 2 by sensitive linkage #1. In order to fully commit to Idea 2, the organisation must first understand how Idea 1 has impacted the business. If Idea 2 is introduced too early it can be seen as the next big thing and all focus will tend towards it and any change made on Idea 1 will be lost. Once Idea 2 has been introduced effectively, leadership must still promote Idea 1 to reduce its inevitable trend towards its pre-change state and plateau in a form that continues to benefit the business. An organisation will rarely change its culture without a change in leadership; a leadership transformation is normally a required precursor prior to an organisational change [18].

7. Conclusion

This paper identifies some factors that determine the current maintenance culture within the RAN and associated support organisations. It further compares the current practices and maintenance cultures within associated industries in a bid to define where more effective maritime support solutions could be. Literature reviewed highlighted how alternative industries and maintenance practices experienced similar challenges to those experienced within the RAN, such as downsizing (through natural attrition and budget restraints) and maintenance outsourcing. Certain aspects of the Rizzo Review were not only applicable to the Amphibious and Afloat Support Ships but to all ships within the RAN fleet. Overall, the maintenance culture could be improved in order to realise an assets true reliability. However, without having the RAN make this decision any changes would likely be short-lived and ineffective due to the RAN being steeped in tradition and wary of change. This paper further identified areas of importance for support organisations. By understanding the current viewpoint of RAN maintainers, support organisations can tailor their support solutions and include ways to ensure maintenance becomes more effective.

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Transdisciplinary Engineering: Crossing Boundaries
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Designing Eco-Effective Reverse Logistics Networks

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Abstract. Reverse Logistics Networks (RLNs) have grown in importance after return policies became compulsory. Lately, questions have been raised whether they are as helpful to the environment as possible. Efforts have been conducted to optimize RLNs in terms of their *eco-efficiency*, minimizing costs and emissions; still, results are not advancing with the necessary speed. Alternatively, the *eco-effectiveness* ("doing the right thing" for the environment) approach emerges, promoting a supportive relationship, balancing environment and economy. This research aims to model the design (or redesign) process of eco-effective RLNs. There are numerous ecodesign tools focusing on product or service design, but an eco-effective design process conceived specifically for logistics network design purposes has yet to be delivered. Research was carried out using the Design Science Research Methodology and an exemplification was outlined to demonstrate how the process unrolls. The model was conceived using a combination of the TRIZ method, Upcycling and Industrial Symbiosis. Eco-efficiency of these networks was not evaluated. The proposed design process model will help the conception of more innovative, eco-effective logistics networks.

Keywords. Upcycle, Reverse Logistics Network Design, Industrial Ecology, TRIZ, Material Flow.

Introduction

Much has been discussed about the role of companies and their manufacturing processes in the development of a truly sustainable world. Measures are being taken by many entities, whether governmental, private, worldwide or regional, but there are still many questions to be answered, with the perception that the approach against environmental deterioration must change [1].

Huge challenges for Sustainable Manufacturing remain in one of its business processes: the **Reverse Logistics** (also called Closed-Loop Supply Chain)**,** which concerns the backward flow for every manufacturing element (e.g. packaging, raw materials) [2]. After sustainable concerns reached industries in general, Reverse Logistics has grown importance by helping decrease environmental impacts. Now a new question emerges: are they being as helpful to the environment as they could be?

Trying to answer this question, major efforts in Closed-Loop Supply Chain (CLSC) have been spent to assess a Reverse Logistics Network (RLN) in terms of its **eco-efficiency –** the ability to deliver the least environmental impact while keeping

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costs as low as possible –, through the development of stochastic and deterministic models that simulate environmental and economic performance using optimization techniques (DEA, Pareto Optimality, MILP, MINLP, and others) [3]–[10].

These researches have contributed significantly to the improvement of RLNs eco-efficiency, but such efforts – considered "oriented for business" by [1]– are not being capable to avoid the increase of environmental burdens: our society is still moving towards a population collapse in 2030 – only fourteen years from now [11]. Bolder initiatives are needed in order to avoid, or at least delay, these outcomes from becoming reality.

In this scenario, the **Upcycling** appears as a concept that is a more effective – or **eco-effective** – design approach, promoting a supportive relationship between environment and economy [12], by leveling their importance in what is considered a **system** approach, accounting for interactions between them while seeking the best performance in both dimensions. After this approach, RLNs now have to be designed (or redesigned, if it is already in place) to Upcycle the environment, what can be achieved by "waste equals food" symbiosis among companies .

In this paper, Design and Redesign will be combined in the sole term (re)design. This research aims to model the (re)design process of Eco-effective Reverse Logistics Networks. The model, represented by a process flowchart, is the artifact that aims to help addressing eco-effective solutions to RLNs. The (re)design flowchart also describes activities, information needed and decisions one has to make while designing eco-effective RLNs. Finally, a short exemplification is proposed to demonstrate its use.

The article is organized starting with a literature review in the Section 1. Section 2 brings in the methodology used to create the flowchart. Section 3 contains the resulting flowchart. Section 4 presents the exemplification of the Poultry Industry and in Section 5, final considerations over the research and its limitations are detailed.

1. Theoretical Background

In source [12], the authors have made an effort to understand main researches in sustainable design and manufacturing domain, where they categorized many initiatives such as Green Supply Chain Management and Industrial Ecology. Both fields of study are somehow related, and, in this section, each concept used for the artifact development is further described.

1.1 Reverse Logistics Design

According to the European Group on Reverse Logistics, Reverse Logistics is "the process of planning, implementing and controlling backward flows of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal" [2]. A typical RLN structure is presented in Figure 1[13]. It shows the forward logistics **-** the classic logistics where finished products are delivered to the market. The Reverse Logistics features the convergent network that takes the end-of-life products back to the recovery facilities, or distribution points.

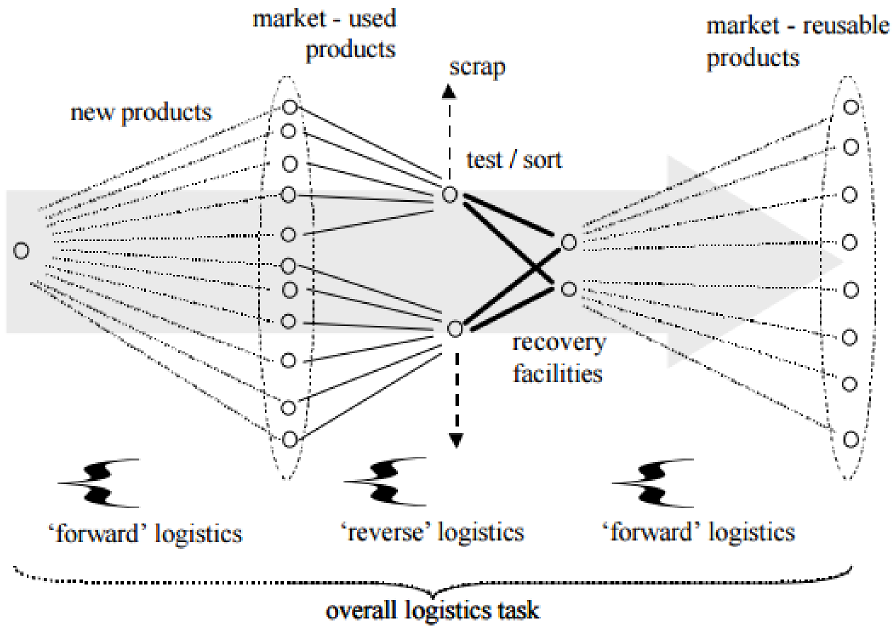

Figure 1. Reverse Logistics Network Structure **(**Fleischmann, 2001).

The eco-effectiveness principles are subject for the next topic.

1.2 Upcycle: being eco-effective

The Upcycle is described in [14] and it represents a change in the design paradigm. Through rethinking design intentions, it is possible to bring benefits to the environment, taking advantage from the undesired outcomes of production processes as stated in their main principle: "waste equals food". Some major points defined as drivers for an eco-effective design are worth describing:

1. **We don't have an energy problem. We have a materials-in-the-wrong place problem.** A designer must not consider how much emission his product is sending in first place: he must ponders if his emissions are going to the right place;
2. **Get "out of sight" out of mind.** Society is used to think about what they put in garbage cans and toilets as worthless material. The authors claim that, instead, these are recipes for nutrients that are probably missing for many other productive activities under development in our communities;
3. **Always be asking on what's next.** Every waste or material that is left behind can be asked endlessly for "what is the next process that it will serve as 'food'?" It does not means that one can use harmful raw materials such as toxic products;
4. **Add good on top of subtracting bad.** The authors state that recognition must be given to everyone who's performing actions to improve the environment;
5. **Gaze at the world around you… Then Begin.** Before designing a solution, one must observe the context and profit from local features;

A discipline that is taking eco-effective measures like "waste equals food" is the Industrial Ecology, which, through Industrial Symbiosis, is promoting industrial relations where waste from one industry is raw material for another productive process, covered in the next section.

1.3 Industrial Ecology

Industrial Ecology is defined as "the exchange of materials between different industrial sectors where the 'waste' output of one industry becomes the 'feedstock' of another." [15]. Material flows are exchanged among companies geographically close together, considering waste as inputs.

In order to enable IE networks, collaboration is fundamental. To support collaboration options, the C4S (Collaboration for Sustainability) tool [16], developed in the SCALE (Step Change in Agri-Food Logistics Eco-Systems) project, was selected. It defines procedures and the activities sequence to put in place new supply partnerships. The process is divided in three phases: preparation, C4S workshop and implementation.

Industrial Ecology is about definining solutions that decreases environmental impacts. In order to generate the upcycle effect, creative, eco-effective material flows have to be defined. Creative design is achieved through methodologies like TRIZ, used in this research and described in the next topic.

1.4 Designing Solutions: TRIZ

TRIZ is an acronym of the Russian "theory of the resolution of invention-related tasks" (in English, TIPS, Theory of Inventive Problem-Solving). It is defined as a "problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature" [17], based on the fact that (i) problems and solutions are often repeated throughout industries and researches and (ii), evolution patterns and creative innovations under development take advantage of effects from researches of other areas [18]. TRIZ is based on the fundamental concepts of Ideality (systems improvement), Contradiction (evolution involves resolution of conflicts), Resources (surroundings can be used to solve the problem), systematization of the problem solving and use of functional diagrams, to represent a problem [19]

Figure 2 represents the strategy of the TRIZ methodology. First it is needed to identify the problem and match it to a general TRIZ problem. If this has been done correctly, a TRIZ general solution (among what is called "TRIZ 40 principles") is found and brought to the specific problem context, represented in the bottom right square. This last analogy will transform the general solution into a specific solution for the problem under investigation. Blue arrows represent analytic activities and the red arrow represents thinking by analogy.

TRIZ main concern is about the conceptual solution of a given problem, whether it contains a contradiction or not [19]. TRIZ general directives determine that, at the highest level, prodution can be achieved with no waste at 100% efficiency, which are in line with Eco-effectiveness principles. Next, methodological procedures will be explained.

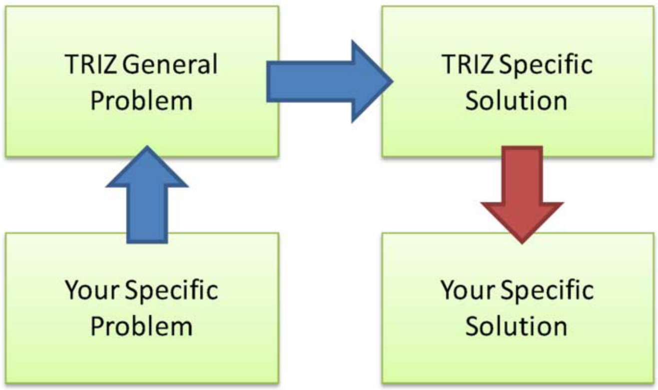

Figure 2. TRIZ Methodology (Barry, Domb and Slocum, 2010).

2. Methodology

This research aims to propose a solution for the problem of Eco-effective Logistics Networks Design. This solution is approached as an artifact and, to develop it, we take advantage of the Design Science Research Methodology (DSRM). [20] present a structured framework of the principles, practices and procedures needed in order to develop a reserch under the domain of the Design Science. Figure 3 represents the framework, which is composed by 6 phases: Problem Identification and Motivation, Definition of the objectives for a solution, Design and Development, Demonstration, Evaluation and Communication.

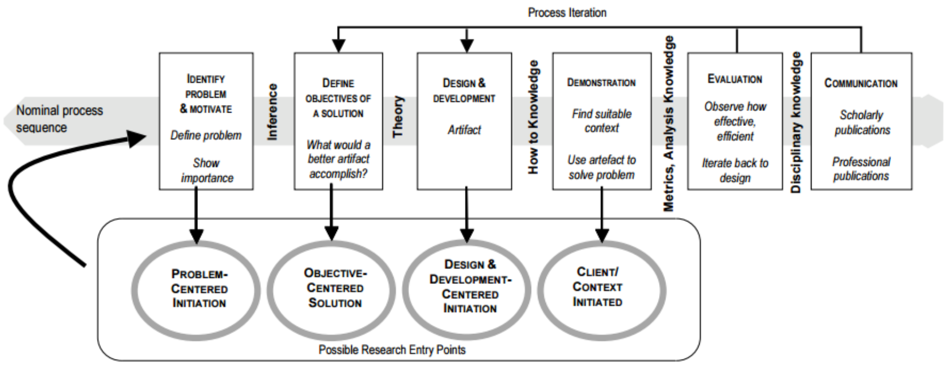

Figure 3. The DSRM structured framework (Peffers et al., 2007).

The first two phases have already been described in section 1: the problem has been delimited and the artifact proposed to solve the problem is a process model. This section is about the Design & Development phase of this model; section 4 will look at Demonstration activities. The Evaluation phase is yet to be performed in future research. Communication will be performed in conferences. Next section will go through the Design and Development phase.

2.1 Artifact Design and Development

First, a representation model was selected after the nature of the artifact being prooposed, in a business process perspective of a "chains of events, activities and decisions that ultimately add value to the organization and its customers." [21]. Business Process Modeling (BPM) was used to create a process flowchart that represents the proposed artifact.

It also necessary to clearly define what an "eco-effective RLN" should be. The Reverse Logistics definition concerns backwards material **flows**: in order to obtain an eco-effective RLN, they must be reviewed. To upcycle the environment, the least processing needed in order to convert waste into inputs, the better. Industrial Ecology is used as a benchmark for upcycling material flow solutions.

As there are many IE initiatives contained in an extensive literature, the design process would benefit from gathering these experiences after the problem has been identified. This information could be grouped in a benchmark database to support the designer during the material flow (re)design process, where he/she could identify possible symbiosis relations to be proposed. In the exceptional cases he/she could not find a solution in the database, the designer will need to create an eco-effective material flow solution. This activity could be performed by means of TRIZ methodology, following its premises and orientations.

After the selection of a solution from the database (or the creation of a new solution), the design process has to look for its feasibility and implementation. C4S methodology helps gathering companies to discuss and implement such new materials and logistics flows. If these new agreements fail to be implemented, the designer will require an alternative path to follow.

3. Findings – the (re)design process flowchart

The RLN Design Process Flowchart is represented in Figure 4, containing events, activities and decisions that take place during the process in order to (re)design an eco-effective Reverse Logistics Network.

The process begins with the activity of mapping the current material flow, where a diagnostic is performed and every material flow – from incoming until final product expedition – is identified. Normally, the designer will have to go through all process stages and facilities to understand the material flow and resources used, e.g. transportation and final destination.

After material flow mapping, the designer can go through the Industrial Ecology Database to search for a similar solution to his/her problem. If a solution can be found in the database, the designer can go forward to the next step: implementation. If not, next step will be to create a solution through a TRIZ-like innovation process.

Following TRIZ methodology, one will go through the TRIZ database and establish potential "waste equals food" relations: starting from the material, he/she must define a solution – what could be done with it? After TRIZ principles, the designer must address these solutions after understanding features from that material like chemical composition, weight and capacity to generate energy.

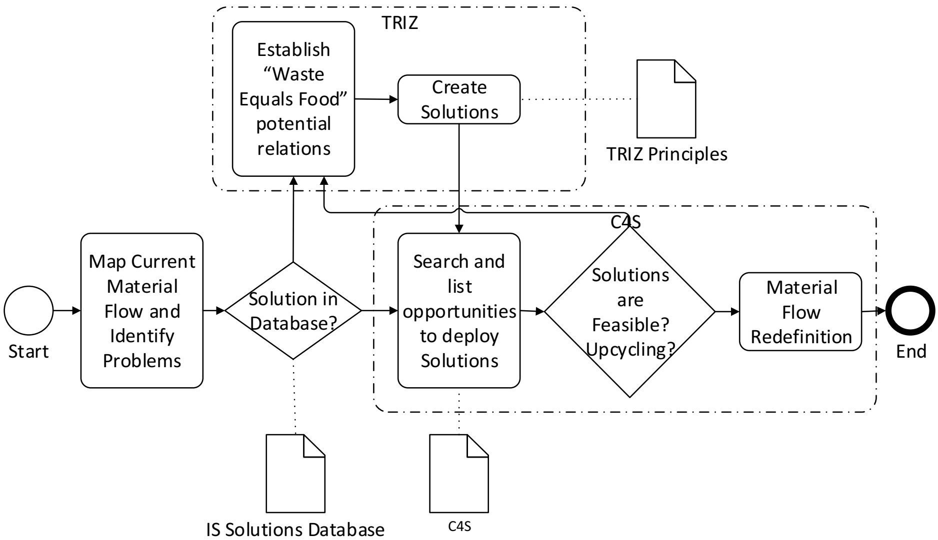

Figure 4. Reverse Logistics Network Design Flowchart.

After completing this activity, he/she can look for opportunities to deploy these solutions, taking advantage of C4S. Locally, the designer can search for entities (e.g. companies, universities) that could receive any of the materials under analysis. When the workshop has finished, one can realize feasible possibilities and evaluate if solutions are indeed eco-effective. If not, the designer will have to restart the TRIZ process and create other solutions for the utilization of the material.

4. Demonstration Example: Poultry Industry

As a demonstration of the above flowchart (according to DSRM's Activity 4), a designer that works for a Poultry Farm that needs to implement Reverse Logistics will map material flows and arrives at results similar to those found in [22]. In this case, searching the database (presented in Table 1, based in [22]), he/she will find eco-effective solutions that could be implemented as a solution. Then, companies that uses the listed materials as inputs for their processes can be mapped.

Table 1. Eco-effective Material Flow Database.

"Waste equals Food" Database				
No.	**"Waste"**	**"Food" for**	**Description**	**Source**
1	Unbroken Rejected Egg	Biscuits and Cakes	Bakery Industry	Shamsuddoha (2011)
2	Broken Rejected Egg	Fish	Fish Industry	
3	Processed Feathers	Bed and Pillow	-	
4	Chicken Paste	Fish	Fish Industry	
5	Poultry litter	Fertilizer	Crop Industry	
		Bio-gas	Energy Generation	
		Charcoal	Energy Generation	

Taking the poultry litter waste as an example, solutions were found in the database: therefore, there was no need to go through steps 4 and 5. The poultry litter can be used in the production of three different materials: fertilizer (by crop industry), bio-gas and charcoal for energy generation. With these three possible solutions, the designer can locally search for industries of such industrial activities. Assuming that two fertilizer companies and one Bio-gas plant have been located – see Figure 5 -, the designer contacts these three companies to propose symbiosis relations with them.

Figure 5 shows that the bio-gas plant is a lot further than fertilizer companies, so it presents a major difficulty for symbiosis at first evaluation. Company "B" stands as the most proximate potential customer for receinving the poultry litter. Fertilizer company "A" has a commercial relation in place with the Poultry Farm, which includes logistics operations with the farm: a truck goes from the fertilizer company "A" loaded with goods and returns empty – this established roundtrip must be considered in the evaluation. Selling to company "B" would require setting a new logistics operation. The designer must compare both alternatives in terms of environmental benefits in order to choose the most eco-effective, using the evaluation model proposed in the next section.

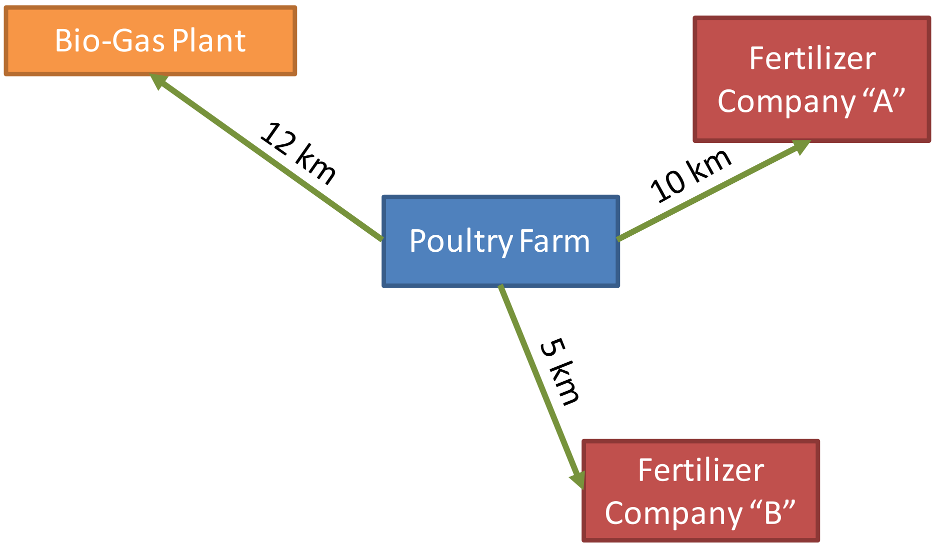

Figure 5. Diagram representing distances from potential symbiosis relations.

4.1 Evaluation Proposal – DSRM Activity 5

Figure 6 describes a model proposal for the direct comparison between material flows. Poultry litter flow from Poultry Farm to current destination presents an environmental impact that can be quantified considering the system in the *X* box. New potential material flows from the Poultry farm to Company "B" (represented by α and α') can be quantified in terms of their environmental impacts – box for systems *Y* and *Y'*. New flows could, sometimes, include transformation processes to adapt this wasted material to be consumed – this is represented in system *Y'*.

To identify quantitatively the benefit achieved by the adoption of a new material flow strategy, the previous impact is subtracted from the new environmental impact and a benefit value is found, represented in Equation 1. The degree of environmental benefit (ΔB) can then be quantified. If the result returns a negative value, there is an increase on the environmental impact.

$$\Delta B_i = Y_i - X \quad (1)$$

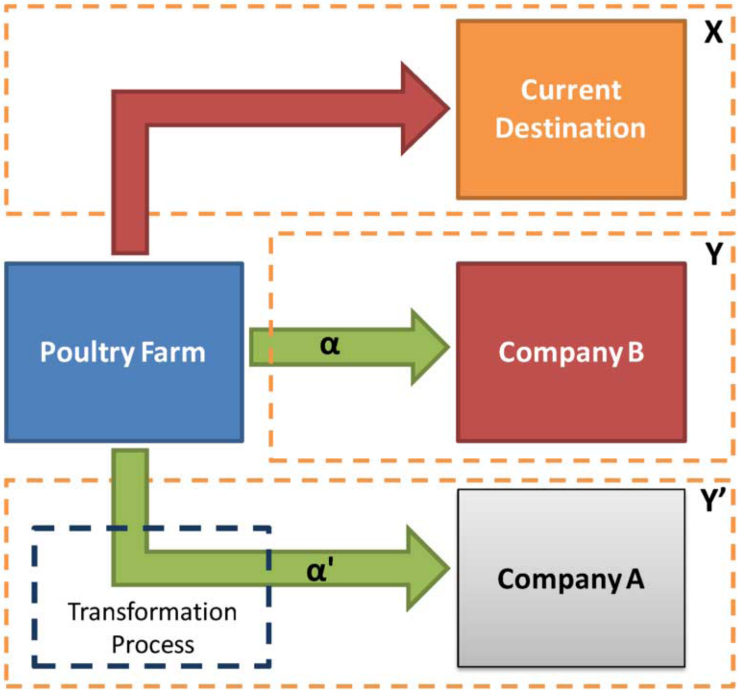

Figure 6. Conceptual model for the evaluation of the new material flow eco-effectiveness.

5. Final Considerations

This paper attempts to define a process flowchart to systematize the design process of Reverse Logistics Networks. It is stated that an eco-effective RLN is the one where material flows are upcycling the environment through "waste equals food" relationships. In order to allow that, a solutions database must be developed using benchmarks such as Industrial Ecology and Industrial Symbiosis.

TRIZ was chosen as the innovation methodology in case there were no previous solution for a specific material flow in the database. Upcycling principles were formalized as guidance to the innovation process. The rest of the process concerns finding and seizing opportunities to deploy solutions and implementing the new material flows.

Under the present study, Reverse Logistics Networks are limited to Client and Supplier and their material flow relations. Aspects of Transportation and routes were not addressed in this research. There was no evaluation of the eco-efficiency of the eco-effective solutions: this is future research that can be performed. Another limitation is that the quantity of waste produced has to be compared with the raw material quantity to be replaced. This research assumed that production volumes are similar. If waste volumes are lower, only a partial benefit is achieved by the symbiosis. If waste volume is higher, more than one symbiosis relation can be established.

Evaluation phase also needs to be better detailed, with indicators and procedures based in Lifecycle Assessment techniques, to support designersto better understand, make decisions and explain benefits achieved through to material flow redefinition. Although it will be very rarely used – as there are "food for" destinations for pratically every type of waste, complementation in the TRIZ process is also needed, to define the proper concepts, ideation techniques and tools among the many available inside the TRIZ methodology. The flowchart needs to be reviewed to better represent the activities for the Reverse Logistics Network definition and singularities from Industrial Symbiosis initiatives.

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Automating Contextualized Maintenance Documentation

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Abstract. Currently, task support information in aircraft maintenance is mostly provided using paper-based solutions, which are burdensome, slow and prone to error. Aircraft maintenance documentation contains vast amounts of information irrelevant for the task at hand and even for the simplest tasks multiple documents need to be consulted. Next to these issues with the documentation itself, Aircraft Maintenance Technicians (AMTs) have very limited on-site access to support information. These factors lead to 15-20% of hands-on-aircraft time being wasted on acquiring the right information or not using maintenance documentation for task support at all, risking maintenance error. This paper describes the development of a system for a first level of contextualization of maintenance documentation to simplify the retrieval of task support information. Combining a tailor-made ontology with a relational database system for Ontology-Based Data Access (OBDA), maintenance documents relevant to a specific aircraft registration mark can be identified. The system contributes to the research field of knowledge management by using OBDA for selecting relevant maintenance documents stored in a regular file folder. Future work will focus on increasing the level of contextualization, development of a mobile tool for on-site access and prototype verification and validation in an operational environment.

Keywords. Aircraft maintenance, maintenance efficiency, contextualized documentation, ontology-based data access, human factors, mobile tools

Introduction

Air transport is well-known for being a very safe and reliable method of transportation. The high level of safety in air transport is achieved while Revenue Passenger-Kilometers (RPKs) have continuously been increasing over the last decade; a trend which is expected to continue at an average rate of approximately 6% a year [1]. One of the most important factors contributing to safety is maintenance, which is based on strict schedules that originated during the development of the Boeing 747. This eventually led to the MSG-3 maintenance approach, now used for all commercial aircraft [2].

A growing market creates challenges from the maintenance perspective. It leads to more required maintenance work, but currently the maintenance workforce is declining [3]. Meanwhile, AMTs require more knowledge to adequately perform maintenance on increasingly complex systems. Acquiring task-specific information is time consuming because aircraft maintenance documentation is notoriously extensive, containing vast amounts of information not directly relevant to execute a task [4], and the information has to be collected from multiple sources. AMTs also have very limited access to task support information; maintenance documentation is usually accessed through workstations (i.e. desktop computers), which are not available in the direct vicinity of the AMT's workplace. This is especially problematic for line AMTs, as the distance from the platform to a workstation can be significant [5]. These issues combined lead to 15-20% of hands-on-aircraft time being wasted on acquiring the right information [6] and negatively affects the operational performance of airline operators by increased turnaround times (TAT) and maintenance errors [7] that lead to increased maintenance costs [8], flight schedule disruptions, major malfunctions [9] and in some cases accidents.

As part of the European Union's Clean Sky 2 research programme, the Airline Maintenance Operations implementation of an E2E Maintenance Service Architecture and its enablers (AIRMES) project aims to develop multiple Integrated Mobile Tools to support the AMT during maintenance tasks. These tools aim to improve maintenance execution efficiency, reduce turnaround times and can lead to cost reductions that are estimated at 195 to 395 M€ annually [10]. Within the scope of AIRMES, a mobile tool for contextualized documentation will be developed to address the weaknesses of maintenance documentation. This paper describes the development of a database system to provide initial contextualization of maintenance documents. Ontology-Based Data Access (OBDA) is implemented to query various types of maintenance documents and is based on a relational database system, a tailor-made ontology and an integrated software platform to query the database. Using the aircraft's registration mark as input, the database system returns the relevant maintenance documents, based on contextual information derived from the registration mark (e.g. aircraft manufacturer, family). Qualitative and quantitative assessment of the database system show very accurate results in retrieving relevant maintenance documents with excellent performance. In the remainder of the paper, human factors in aircraft maintenance are discussed first, followed by the development of the database system and a discussion of the results obtained. Finally, conclusions are drawn and future research is identified.

1. Human factors in aircraft maintenance

To understand how AMTs currently use maintenance documentation, knowledge of the human factors involved is essential. Human error has been defined in different ways, but all share the idea that, for one, humans are organic mechanisms with failure rates and tolerances similar to hardware and software elements of a system, and secondly, human error is a negative term for normal human behavior in less than ideal environments [11]. Several models were developed to find causes for human error in aviation maintenance and the most well-known model for human factors that lead to error was developed by Gordon Dupont in 1993, known as the "Dirty Dozen" [12].

In 2008, Hobbs investigated the conditions in which AMTs work and identified resulting physical (e.g. omissions) and psychological actions (e.g. wrong assumptions) that lead to error [13]. AMTs are confronted with exceptional circumstances; adverse weather, physical and spatial challenges and the unique sense of stress because the work performed can influence the safety of future flights. Line maintenance is performed within the flight schedule and creates an increased sense of pressure on the

AMT to fulfill maintenance tasks on time to avoid flight disruptions. Time pressure typically increases the chance of individual errors as result of memory lapses and procedural violations. Poor maintenance procedures and documentation can also lead to errors. The FAA found that AMTs spend 25-40% of their time dealing with maintenance documentation, including administrative work [13; 14]. Procedures and manuals are often impractical to use; prescribed procedures are not in agreement with the way an AMT performs a task and manuals are written with extensive use of warnings, complicating extraction of useful information. Access to maintenance documentation is also limited, especially for line AMTs working on the platform: depending on the layout of the airport this can take up to half an hour [5]. The issues with maintenance documentation result in a continuous trade-off being made by AMTs when they need to consult task-specific information [15]. A study showed that the AMT will only look for the required information if the benefit or value of that information exceeds the cost (e.g. time, effort) to acquire it. The AMT individually determines the added value of the documentation based on experience (risking complacency), but also based on previous experience with maintenance documentation [16]. These findings, together with the strong relation between aviation maintenance errors and the content and (non-)use of maintenance documentation [7; 9], show the importance of using correct, complete and relevant maintenance documentation during task execution.

2. Development of a proof of concept for contextualized documentation

To address the weaknesses of maintenance documentation and its implications, this work introduces a proof of concept to contextualize maintenance documentation. The developed system includes a tailor-made ontology, a relational database system containing maintenance documentation and the fleet information, as well as a software solution to integrate the ontology for Ontology-Based Data Access (OBDA).

2.1 Ontology development

The database system uses a concept developed in previous work by Lattner and Apitz [17], which uses metadata captured in ontologies to contextualize information. The use of an ontology to structure and classify information in a database system has several benefits [18], including: sharing a common understanding of the structure of information, enabling reuse of domain knowledge, making domain assumptions explicit (i.e. assumptions can easily be changed when knowledge about the domain changes) and separating domain knowledge from operational knowledge. Especially in an innovative industry like aviation, where new knowledge continuously becomes available, the benefit of using an ontology to describe the domain is evident. To be able to establish relations between the registration marks in a fleet and the maintenance documents related to it, an ontology representing the aircraft models in the fleet is required. With no ontology readily available, an ontology was developed based on the fleet of KLM Royal Dutch Airlines using Stanford's open-source ontology editor Protégé. Table 1 shows a sample of KLM's fleet information, with the registration mark (Reg) and aircraft type (Aircraft Type) as relevant information for the ontology.

Table 1. A sample of KLM's fleet information.

Reg	Aircraft Type	Aircraft Name	Age
PH-AKA	Airbus A330-303	Times Square - New York	3.5 Years
PH-AKB	Airbus A330-303	Piazza Navona - Roma	3.5 Years
PH-BGN	Boeing 737-7K2 NG	Jan van Gent / Gannet	4.4 Years
PH-BGO	Boeing 737-7K2 NG	Paradijsvogel / Bird of Paradise	4.4 Years

Following from the registration mark the aircraft type can be determined and contextual information can be extracted. For example, registration mark PH-AKA has manufacturer Airbus and belongs to the A330 family. Figure 1 shows the part of the ontology for registration mark PH-AKA, showing the relations between aircraft type "Airbus A330-303" and its related classes: "Airbus" (hasManufacturer), "A330" (hasFamily). Other classes defined in the ontology were discarded for the proof of concept, because relations could not be established consistently (e.g. engine models and aircraft version) or including the information would lead to unreliable results (aircraft series, discussed in section 3.1). The ontology also includes relationships not shown in Figure 1, for example disjoints between manufacturers (e.g. Boeing is disjoint with Airbus) and disjoints between aircraft families (e.g. A330 is disjoint with A350 and A380). One of the benefits of a properly defined ontology is that new classes or individuals can automatically be classified by a reasoner through inference and thereby inherit all the properties of the class it is assigned to.

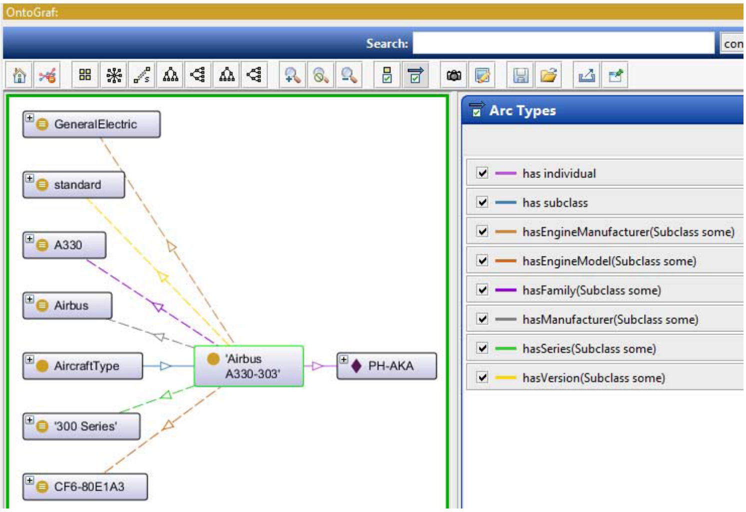

Figure 1. Graphical representation of the aircraft type ontology in Protégé.

2.2 Database development

With the ontology available, a database for the maintenance documents was set up. Because most maintenance documents are available in the Portable Document Format (PDF), the goal was to use a system that can directly use this file format. Database systems can work with Binary Large Objects (BLOBS) like PDF files in two ways: store them directly in the database, which can cause performance issues with larger files [19], or store them in a separate file system. A separate file system provides good performance, also for larger files such as Aircraft Maintenance Manuals (AMMs), but generally lacks the integration of essential functionality for the task at hand, namely full-text search. Currently, the only solution available to work with a separate file system and have full-text search functionality is provided by the FileTable feature in Microsoft's SQL Server (2012 and later). The FileTable feature can access and search within maintenance documents, stored in a regular (network) file folder, in their unstructured, original file format. Hence, a Microsoft (MS) SQL Server with the FileTable feature enabled was set up with access to a set of maintenance documents in a network file folder.

Next to the maintenance documents, a table with the fleet information was imported into the database in order to link registration marks from the fleet to aircraft type classes in the ontology. The registration marks could be included in the ontology directly, but this is deliberately avoided to keep the ontology independent from the airline the system is used for. This way, the ontology can be used for any fleet that is imported into the database, provided all the aircraft types in the fleet are described in the ontology. Using a script, distinct columns for the aircraft manufacturer, family and series were automatically added to the fleet information table to be able to establish links with the corresponding classes in the ontology. The resulting SQL database table is shown in Figure 2.

	reg	AircraftType	AircraftName	Age	Manufacturer	Family	Series	Model
1	PH-AKA	Airbus A330-303	Times Square - New York	3.5 Years	Airbus	A330	300	Airbus A330-300
2	PH-AKB	Airbus A330-303	Piazza Navona - Roma	3.5 Years	Airbus	A330	300	Airbus A330-300
3	PH-AKD	Airbus A330-303	Plaza de la Cathedral - Habana	3.4 Years	Airbus	A330	300	Airbus A330-300
4	PH-AKE	Airbus A330-303	Praça de Rossio - Lisboa	2.6 Years	Airbus	A330	300	Airbus A330-300
5	PH-AKF	Airbus A330-303	Hofplein - Rotterdam	0.8 Years	Airbus	A330	300	Airbus A330-300

Figure 2. Sample of the modified KLM fleet information in the database.

With separate columns for the manufacturer, family and series information, links with the related classes in the ontology can be made by using so-called mappings.

2.3 Linking the ontology to the database for OBDA

Multiple methods for mapping of ontologies onto relational databases are available, all having specific benefits and drawbacks. A recent survey of state-of-the-art methods for automatic and lossless mapping of ontologies onto relational databases has shown that the several available methods still have issues with loss of structure, loss of information or are not fully automatic [20]. A new, promising method is provided by Ontop, developed at the Free University of Bozen-Bolzano in Italy. Although the method does not support automatic mappings, it proves to be one of the best approaches for OBDA. Unlike other methods, which have the ontology as a virtual layer between the source database and the query engine, Ontop provides direct access to the sources, the ontology and the mappings (Figure 3), avoiding loss of metadata and performance or memory issues the other approaches have. Ontop is provided as a plugin for Protégé and consists of a tool for creating mappings as well as a reasoner and query engine, enabling on-the-fly querying of the underlying database using the SPARQL query language [21]. Quest has superior SPARQL-to-SQL translations compared to other systems and outperforms any other known methods for OBDA, such as Virtuoso RDF Views and D2RQ [22].

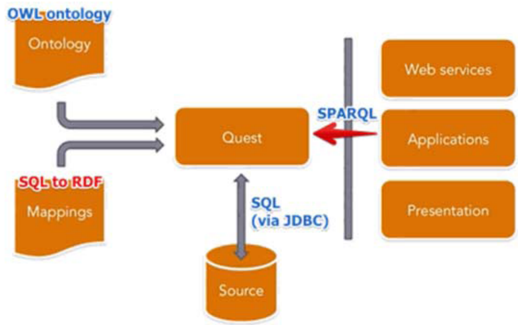

Figure 3. The Ontop framework.

Using Ontop and its plugin for Protégé, a total of 35 mappings were created. A mapping consists of a mapping identifier, a target and a source. The source refers to specific information in a database table, the target states a set of RDF triples and the mapping identifier is simply used to name the mapping. RDF triples state relationships between resources and always consist of a subject, a predicate and an object.

```
Manufacturer-Airbus
  :{Manufacturer}/{Reg} a :Airbus ; :hasModel {Model} ; :hasManufacturer {Manufacturer} ; :hasFamily {Family} ;
  :hasSeries {Series} ; :namedType {AircraftType} ; :name {AircraftName} ; :age {Age} .
  SELECT * FROM FleetInfoKLM WHERE Manufacturer = 'Airbus'
```

Figure 4. Manufacturer mapping for Airbus.

Figure 4 shows an example of a mapping to link registration marks in the database table having manufacturer Airbus to the class Airbus in the ontology. Similarly, mappings were made to link all relevant columns in the database table to classes in the ontology. The final mappings establish a link between a distinct aircraft model, 9 in the case of KLM, and its related maintenance documents. An example of such a mapping is shown in Figure 5. The target relates the subject, a registration mark, to an aircraft class and its related documents. Relevant documents are identified in the source of the mapping, where information from the fleet information database table is joined with information in the maintenance document FileTable, under the condition that specific keywords are found in the document (i.e. defined in the WHERE statement).

```
A330-303-Docs
  :{Model}/{Manufacturer}/{Family}/{Series}/{Reg} a :A330-303 ; :docName {name} .
  SELECT FleetInfoKLM.Reg, FleetInfoKLM.Model, FleetInfoKLM.Manufacturer, FleetInfoKLM.Family, FleetInfoKLM.Series,
  MaintenanceDocumentation.name, MaintenanceDocumentation.path_locator FROM MaintenanceDocumentation
  JOIN FleetInfoKLM
  ON FleetInfoKLM.Manufacturer ='Airbus' AND FleetInfoKLM.Family ='A330' AND FleetInfoKLM.Series ='300'
  WHERE (CONTAINS(file_stream,'Airbus') AND CONTAINS(file_stream,'A330'));
```

Figure 5. Mapping to relate the aircraft model A330-303 to its related documents.

With all required mappings available, relevant maintenance documents in the database can be identified by entering a registration mark in the SPARQL query engine. From the registration mark contextual information about the manufacturer, family and series is obtained to full-text search maintenance documents for the associated keywords with the FileTable feature. When the keywords are identified in a maintenance document, the document is returned as relevant. The result of a query for registration mark "PH-AKA" is shown in Figure 6.

Registration	Name	Model
:Airbus%20A330-300/Airbus/A330/300/PH-AKA	"EASA_AD_2014-0148_1.pdf"	<Airbus A330-300>
:Airbus%20A330-300/Airbus/A330/300/PH-AKA	"EASA_AD_2014-0248_1.pdf"	<Airbus A330-300>

Figure 6. Result for relevant maintenance documents for PH-AKA.

3. System results

The developed database system was assessed with regard to quality and performance, using freely available Airworthiness Directives (ADs). For each of the distinct aircraft families in the KLM fleet, being Boeing 737/747/777/787 and the Airbus A330, 2 ADs are added to the database per batch, after which the respective tests are performed.

3.1 Qualitative assessment

To test if the system returns the correct relevant maintenance documents, a qualitative assessment was performed over the first batch of 10 ADs. For this, results of the full-text search function of the FileTable were compared with a manual search through the documents to verify that the keywords for manufacturer, family and series information of an aircraft registration mark are correctly identified in the documents. The qualitative assessment showed that inclusion of the series information leads to unreliable results. This is caused by two factors. Firstly, the command used by the FileTable feature searches documents for exact keyword matches; when an AD refers to "*Airbus A330-201*", the FileTable keyword search will not find a match with the Airbus 200 series. This is beneficial to avoid false positives based on other information containing the x00 format, such as the year 2006, but prevents the system to identify documents relevant to a specific aircraft series. Secondly, the series information is not always stated in the AD. Documents may refer to "*all series*" of a family, and thus an exact match for a specific aircraft series cannot be found. More advanced methods for the full-text search implementation may be developed to overcome these issues, but are not included in this initial proof of concept. Hence, the aircraft series information was omitted in further assessments.

3.2 Performance assessment

The assessment was continued with a focus on the performance by determining the impact on query runtime when the number of available maintenance documents in the database is gradually increased by batches of 10 ADs. Starting with a batch of 10 documents, one registration mark for each of the 9 distinct aircraft models in KLM's fleet is used as input to query the database for relevant maintenance documents. The performance is measured by the query runtime, defined as the time from initiating the query until displaying the result. This is repeated five times per batch for every registration mark, leading to a total of 45 measurements per batch.

Query runtimes were measured for a method with and without OBDA integration (referred to as OBDA and SQL, respectively) to be able to assess the effect of using an ontology on query runtime. Querying the database without OBDA implementation is possible because the current database structure is still relatively simple. Once the complexity increases, for example when engine model information is added, the benefits of OBDA (i.e. having a high-level, easily adaptable structure independent from the database structure) become more evident. The results are plotted in Figure 7, with on the horizontal axis the batch number and on the vertical axis the average query runtime of 45 measurements per method. It shows that the OBDA method initially has lower performance than the SQL method, but from batch 2 onwards consistently outperforms the SQL method by approximately a factor 2.

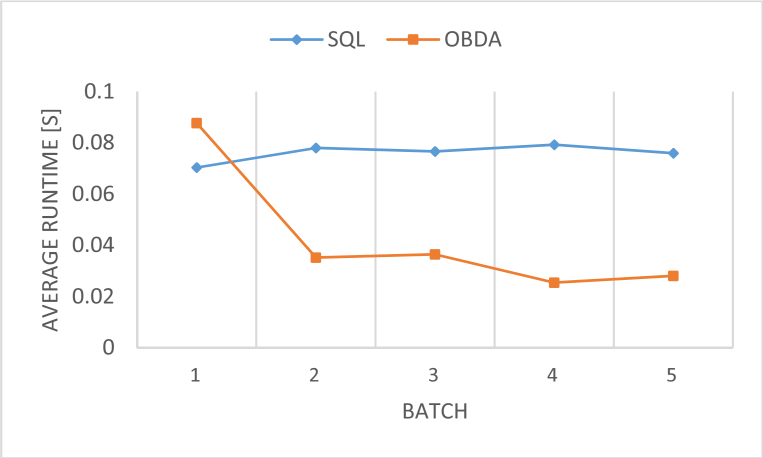

Figure 7. Average query runtime per batch for SQL and OBDA.

The results are remarkable considering that the developers of Ontop confirmed that table joins in the source of the mappings, as well as the CONTAINS statement used for the full-text search in the FileTable feature, are not fully supported. Moreover, the OBDA method requires extra processing to link the database with the ontology through mappings. Further tests showed similar behavior and more research is required to determine the cause.

4. Conclusions

A database system was developed to retrieve relevant maintenance documents, using the aircraft registration mark as input. The core of the database system is Microsoft SQL Server and the maintenance documentation stored in a FileTable with full-text search functionality. An approach for OBDA was pursued to benefit from the high-level conceptual schema, relations and domain knowledge of an ontology. To implement OBDA, an ontology for the domain of commercial aircraft was developed and integrated using the Ontop plugin for Protégé. Qualitative and quantitative assessments showed that fast and reliable results can be obtained when the series information is discarded. After initialization, the OBDA approach retrieves relevant maintenance documents approximately twice as fast as SQL.

The OBDA method contributes to the research field of knowledge management by providing OBDA for unstructured data, such as maintenance documents in PDF, by using the FileTable feature of Microsoft SQL Server in combination with Ontop for ontology integration. While the level of contextualization of the database system is limited, it provides a functional proof of concept for contextualizing maintenance documentation. The methodology can be applied to other domains by substituting the ontology and alter the mappings accordingly.

Current disadvantages of the developed system are the dependency on Microsoft's FileTable feature, including its incompatibilities with Ontop, and lack of support for automated mappings. These disadvantages will be addressed in future work, which will also focus on increased levels of contextualization, development of a mobile tool for on-site access and prototype verification and validation in an operational environment to assess potential time and cost savings. Such a system does not only tackle the limited accessibility for line maintenance technicians, but also improves the usability of maintenance documentation, and could significantly reduce the time currently wasted on acquiring task-specific information. The likelihood of both flight schedule disruptions and maintenance errors will be reduced, thereby increasing the operational efficiency and overall safety of air transport.

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Amorphous Transdisciplinary Engineering: Object Orientation Meets Service Orientation with Emergent Multifidelity Management

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Abstract. Amorphous transdisciplinary engineering is the application of back-end object-oriented provider services and front-end service-oriented micro- and macro-services. Macroservices define dynamic aggregates of large number of provider services (applications, tools, and utilities) with emergent multifidelity management. On the one hand, provider services are local/remote objects having independent limited functionalities that are dynamically bound to microservices. On the other hand, macroservices are request services in terms of microservices and other macroservices with metafidelities that specify required federations of provider services. Metafidelities are fidelities of fidelities. A metafidelity is used by a fidelity management system to select (morph) for a macroservice a collection of microservices at runtime. A macroservice request is called a mograms – model or program, or both. Service mograms created by the end users at the system of system level exhibit emergent behavior of service federations at runtime. A mogram's service federation with associated fidelity management is continuously morphing to the most effective collections of provider services while skipping unsatisfactory transient federations at runtime.

Keywords. Service orientation, microservices, macroservices, provider services, multifidelities. metafidelities, metacomputing, MOF, MSF, system od systems, mogramming, exertions, SML, SORCER

Introduction

Amorphous transdisciplinary engineering (ATE) is the broad usage of heterogeneous computer software for both standalone and distributed systems to aid in complex and adaptive engineering analysis tasks. It integrates various tools from multiple engineering domains including Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Multibody dynamics (MBD), and Multidisciplinary Analysis and Design Optimization (MADO).

MADO is a domain of research that studies the dynamic application of numerical analysis and optimization techniques for the design of engineering systems involving multiple disciplines. The formulation of MADO problems has become increasingly complex as the number of engineering disciplines and design variables included in typical studies has grown from a few dozen to thousands when applying high-fidelity physics-based modeling early in the design process [1].

Software tools that have been developed to support MADO activities are considered ATE tools. There are several trends that are forcing system architectures to evolve due to complexity of engineering problems being solved presently [1]. Users expect a rich, interactive and dynamic user experience on a wide variety of user agents (clients) and highly modular and dynamic systems. Systems must be highly scalable, highly available and run locally or in the network, or both. Organizations often want to frequently roll out updates, even multiple times a day. Consequently, it's no longer adequate to develop simple, monolithic web applications that serve up HTML to desktop browsers. When the dynamic system changes frequently the static user agent cannot catch-up with the backend changes, so it becomes quickly obsolete in evolving complex adaptive systems. In a dynamic system when its backend is morphing constantly - *amorphous system* - the user agent has to be amorphous accordingly. A service-oriented (SO) amorphous system means also *net-centric* to refer to participating as a part of a continuously evolving complex community of people, devices, information and services interconnected by a communications network to achieve optimal benefit of resources and better synchronization of events and their consequences. An amorphous system means also *scalable* and *autonomic* so your communication network of services can be scaled up and down reliably, from a single computer to a large number of computers as needed at runtime.

Recent most popular distributed architectures are based on a service-oriented architecture (SOA) [2]. It is an architectural pattern in computer software design in which application components provide services to other components via a communication protocol, typically over a network. However, SOA-based systems are still very difficult for most users to access, and that detailed and low-level programming must be carried out by the user through command line and script execution to carefully tailor static interactions on each end to the distributed resources on which they will run, or for the data structure that they will access. Most of these architectures in fact represent Service-Disoriented Architecture (SDA). In SDA the notion of service is ill defined with no clear properties such as instantiation, multifidelity, inheritance, polymorphism, composition, delegation, well-defined service lifecycle, etc.; not mentioning confusing SO terminology that is oriented usually on something else except uniform services, in contrast for example to uniform objects in object-oriented systems. With that in mind in Section 1 more formal definitions are provided for uniform front/back-end services and federated amorphous systems.

The Service-ORiented Computing EnviRonment (SORCER) [2] adheres to a true SO architecture that has been developed and applied to solve multidisciplinary design-optimization problems with multifidelity services allowing for integration multiple data sources and tools as morphing service federation. Its true service-orientation means that all system data and operations are uniform services. The unique architecture is about organizational complexity and system complexity that allows treating local and remote service uniformly at various levels of granularity. When dealing with both complexities, you have a case to distribute, otherwise create a modular monolith with locally executable modules as local services. Later, when complexity of the system becomes too complex to manage you can deploy almost instantly the existing local modules as network services on an as-needed basis and then run selected modules of the original monolith in the network. Such SORCER application is accomplished using service signatures that require a change of service types only or just selecting service fidelities from local to remote when requesting services.

The remainder of this paper is organized as follows: Section 1 describes a conceptual service-oriented framework of federated amorphous systems; Section 2 describes the reference architecture of the modeling and execution framework; Section 3 describes N^3 diagraming and mogramming MADO systems; finally Section 4 concludes with final remarks and comments.

1. Service Orientation and Federated Amorphous Systems

In general, a *computing service* is the work performed in which a service provider (one that serves) exerts acquired abilities to execute a computation. SO architecture (SOA) is an architectural pattern in computer software design in which application components provide services to other components via a communications protocol, typically via remote procedure call (RPC). Application components that provide services to other components are called *provider services.* Well-defined SOA is a *service-to-service* (S2S) application architecture that partitions workloads among uniform provider services (service peers).

Six generations of RPC can be distinguished including a federated method invocation (FMI) [1]. The signature based FMI has been used to develop a federated SO environment [2] based on the conceptual SO framework described in this section.

1.1. Service-oriented Terms and Definitions

Federated SO computing studies *computational federations* that are dynamic collections of collaborating services. Five types of basic services are distinguished: context services, microservices, multifidelity services, macroservices, and provider services. *Context services* provide *data* other services operate on. *Microservices* are elementary services. *Provider services* are realizations of microservices; it means that for each microservice there is at least one corresponding actualization – a *provider service*. *Macroservices* are compound services – compositions of microservices and other macroservices. Macroservices represent abstract service models that are actualized by corresponding collections of provider services as their concrete dynamic service systems.

A *context service* is a collection of *named entries* such that each name is uniquely associated with a constant value (*value entry*), evaluated value (*evaluated entry*), or exerted value (*service entry*). An evaluated or exerted entry in its context-service scope is a functional composition that depends on other entries of that scope. Given the set ES of all entries, the set of context services CSS is the powerset of entries $\mathcal{P}(ES)$. Context services with value entries only are called *data model services* and denoted by DMS. Context services that contain service entries are called *context model services* and denoted by CMS. Therefore, the set of context services CSS is the union

$$CSS = DMS \cup CMS. \tag{1}$$

The *context realization* r_c is the following mapping:

$$r_c : CSS \times DMS \longrightarrow \{ true, false \} \tag{2}$$

that defines the meaning of context services. If the realization $r_c(incss, outdms)$ of input context model service *incss* into output data model service *outdms* equals to *true*, then it is said that context model *incss* is *valid* for the data model *outdms*, otherwise is *invalid*.

The elementary service realization r_e is the mapping

$$r_e : MISS \longrightarrow PSS \tag{3}$$

where *MISS* is a set of microservices and *PSS* is a set of provider services.

The set of all component services for macroservice *mas* is given by the function *cs*:

$$cs : MASS \longrightarrow \mathcal{P}(MASS) \tag{4a}$$

and the set of all component microservices for macroservice *mas* is given by the function *cms*

$$cms : MASS \longrightarrow \mathcal{P}(MISS) \tag{4b}$$

The *federated binding b* is the mapping defined as follows:

$$b : MASS \longrightarrow \mathcal{P}(PSS) \tag{5}$$

such that for each macroservice $mas \in MASS$ and each $mis \in cms(mas)$ (4b), $r_e(mis) \in b(mas)$, where *MASS* is the set of macroservices and $\mathcal{P}(PSS)$ is the powerset of provider services. The set of provider services $b(mas)$ is called a *service federation* of macroservice *mas*.

For each macroservice $mas \in MASS$ multiple service federations F_i, $i = 1, 2, \ldots$, n are actualized by the *federated realization* r_f as follows:

$$r_f : MASS \longrightarrow \{ F_i \} \tag{6}$$

such that for each federations F_i exits the binding $b(mcs) = F_i$. Multiple federations for a macroservice are in existence to provide system reliability in the presence of provider service replication.

The macroservice such that any named subset of its component services is used as a service is called a *multifidelity service*. A *service projection* p_s of the *multifidelity service mfs* is the mapping:

$$p_s : FI \times MFSS \longrightarrow \mathcal{P}(cs(mfs)) \tag{7}$$

such that $p_s(fi, mfs) \in \mathcal{P}(cs(mfs))$ (4a), where *FI* is the set of fidelities, $fi \in FI$, *MFSS* the set of multifidelity services, $mfs \in MFSS$, and $cs(mfs) \subseteq MASS$ is the set of all component services of *mfs*. In particular, fidelities may refer to singletons of $cs(mfs)$.

The set of *all macroservice MASS* is a set defined as follows: (8)

i. if $s \in MISS$ then $\{ s \} \in MASS$
ii. if $s \in CSS$ then $\{ s \} \in MASS$
iii. if $s \in MFSS$ then $\{ s \} \in MASS$
iv. $s \in \mathcal{P}(MASS)$ then $s \in MASS$

Each macroservice is a set associated with a hierarchically organized *component services* as defined in i-iv. In other words, a *macroservice* is a *collection of services* hierarchically composed of context, micro, multifidelity, and other macroservices. Multifidelity services are associated with *service projections* (7) that can be invoked at runtime to create another instance of the metasystem. Each macroservice with federated realization r_f (6) can be *bound* to at least one federation of available provider services. When service fidelities are updated then related service federations adapt in size and quality as needed.

A morphing projection p_m is the mapping

$$p_m : MFI \longrightarrow \mathcal{P}(FI) \tag{9}$$

assigning for each metafidelity a corresponding set of service fidelities, where *MFI* is the set of all metafidelities and $\mathcal{P}(FI)$ is the powerset of all service fidelities such that for each metafidelity *mfi*, $p_m(mfi) \subseteq FI$, for $mfi \in MFI$.

Projection functions p_s and p_m define service and metafidelities service that allow for adaptivity of system-of-systems when updates of fidelities are controlled by fidelity management at runtime as illustrated in **Figure 1**.

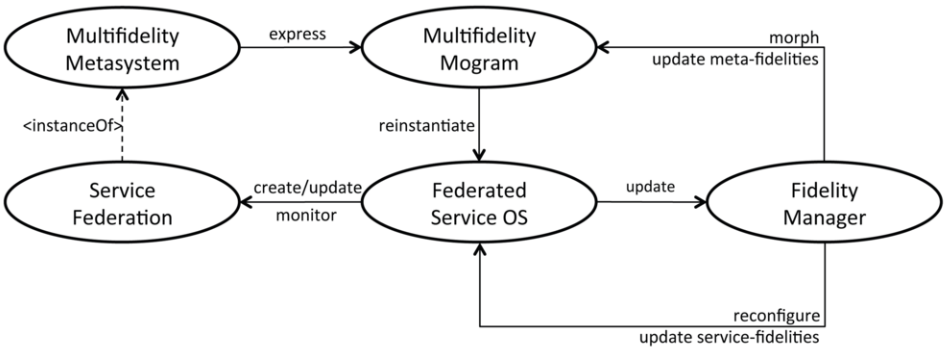

Figure 1. Morphing and reconfiguring mograms by a federated service opertaing system (OS)

Adaptive federated SO systems with varying metafidelities at runtime are called *federated amorphous systems*. This type of systems exhibits three types of adaptivities called *system-of-system* (metasystem), *system*, and *service* agilities. Metasystem agility refers to updating metafidelities (system reinstantiation - morphing), system agility refers to updating service fidelities (system reconfiguration), and service agility refers to selecting relevant fidelities of individual provider services.

1.2. Federated Amorphous Systems

The federated amorphous system (*FAS*) is a triplet (service system, multifidelity system, system-of-systems) of triplets:

$$FAS = \langle\langle CSS, MISS, PSS \rangle, \langle MFSS, FI, p_s \rangle, \langle MFI, p_m, \langle r_c, r_e, r_f \rangle\rangle\rangle \quad (10)$$

where

a) *CSS*, *MISS*, *PSS*, *MFSS* are sets of context, micro, provider, and multifidelity services respectively;
b) Macroservices are compound services with hierarchically organized component services in *MASS* (8);
c) p_s: $FI \times MFSS \longrightarrow \mathcal{P}(MASS)$ is a *service projection* (7) such that $p_s(fi, mfs)$ is the subset of component services of *mfs*, where fidelity $fi \in FI$ and multifidelity service $mfs \in MASS$;
d) $p_m : MFI \longrightarrow \mathcal{P}(FI)$ is the *morphing projection* (9) such that for each metafidelity *mfi*, $p_m(mfi) \subseteq FI$, for $mfi \in MFI$;
e) $r_c : CSS \times DMS \longrightarrow \{ true, false \}$ is the *context realization* (2) that defines the meaning of context models;

f) $r_e : MISS \longrightarrow PSS$ is the *elementary service realization* (3) such that for each $s \in MISS$, $r_e(s) \in PSS$;

g) $r_f : MASS \longrightarrow \mathcal{P}(PSS)$ is the *federated realization* (6) such that for each $s \in MASS$, $r_f(s) \in \mathcal{P}(PSS)$;

h) *service reification* in *FAS* is the mapping $ri : MASS \longrightarrow PSS$ such that a macroservice $mas \in MASS$ is converted into a provider service $ri(mas) \in PSS$;

i) *service provisioning* in *FAS* is the mapping $pr: MASS \longrightarrow \mathcal{P}(PSS)$ such that $pr(mas) = r_f(mas)$ and $pr(mas) \subseteq PSS$ for each macroservice $mas \in MASS$; and

j) *evaluation* of microservice $mas \in MASS$, is the mapping

$$e: MASS \times CMS \times \mathcal{P}(MFI) \times \mathcal{P}(FI) \longrightarrow DMS \tag{11}$$

such that for macroservice *mas* and input model service $incm \in CMS$, $MFI_{mas} \subseteq MFI$, and $FI_{mas} \subseteq FI$, exits federation $F_{mas} \subseteq \mathcal{P}(PSS)$ and the corresponding output model service $outdm = e(mas, incm, MFI_{mas}, FI_{mas})$ provided $r_f(mas) = F_{mas}$ and $r_c(incm, outdm) = true$. Service evaluations are consistent with the morphing/service projections, service reification, and provisioning functions. The feedback to parent services how to morph/update fidelities is driven by observed actions of provider services. In particular, evaluation of context service $cs \in CSS$ is the mapping

$$e: CSS \times CMS \times \mathcal{P}(MFI) \times \mathcal{P}(FI) \longrightarrow DMS \tag{12}$$

such that for each context model $cm \in CSS$ the corresponding output model service $outdm = e(cm, incm, MFI_{mas}, FI_{mas})$, provided *incm* is the context scope for each entry in c*m* to be evaluated as the functional composition with dependent entries in both *cm* and *incm*.

The federated service system reduced to a *client-server system* (C/S) is defined as follows:

$$FAS = \ll DMS, \{ client \}, \{ server \}>, < r_c, r_e, r_f \gg \tag{13}$$

where the set of microservices *MISS* is reduced to one *client* and provider services *PSS* is reduced to one provider *server* with $r_e(client) = server$, $r_f(client) = \{ server \}$, and r_c is just the server mapping from data input to data output. The end users in C/S do not have any frontend control regarding how the server would collaborate with other servers. No frontend macroservices, only single microservice (client) to the static backed seen as the black box by the end users.

When all fidelities in *FAS* do not change at runtime, the system is called the *static* multifidelity *FAS*, otherwise is called the *amorphous FAS*. System realization and configuration functions: r_c, r_e, r_f, p_s, p_m, *ri*, and *pr* define the essential dynamic configuration support for managing amorphousness of the complex adaptive *FAS.*

Note that a hierarchically organized macroservices are evaluated with context services as evaluation arguments. Here, service evaluation arguments – data or context models – are services as well. On the one hand, macroservices can be defined as hierarchically composed services (8). On the other hand, values of context model entries can be macroservices and then used as arguments of functional compositions defined by other entries within the same context service (1). The former compositions are called exertions; the latter are called context models. Defining service data and operations as uniform system of services is referred to the “true service-oriented architecture" in contrast to other so called "service-oriented" architectures lacking this type of service uniformity.

2. Service-oriented Computing Environment (SORCER)

2.1. The SORCER Four-layer Metamodel Hierarchy

The SORCER meta-metamodeling layer, called SORCER Meta Service Facility (MSF) is the foundation of the service-oriented metamodeling hierarchy by the analogy to the object-oriented the metamodeling hierarchy of OMG Meta Object Facility (MOF) [3]. The primary responsibility of this layer is to define the language for specifying a metamodel. The layer is often referred to as M3, and FAS is an example of a meta-metamodel. A mathematical meta-metamodel is typically more compact than a metamodel - SML (Service Modeling Language). An SML is an instance of FAS, meaning that every element of SML is an instance of an element in FAS. The primary responsibility of the SML layer is to define a language for specifying service models in the form of service mograms. The metamodel layer is often referred to as M2; the UML metamodel is an instance of the MOF and the SML metamodel is an instance of the MSF as illustrated in **Figure 2**.

A model is an instance of a metamodel. The primary responsibility of the model layer is to define languages that describe semantic domains to allow users to model a wide variety of different problem domains in particular to express various types of SO processes. The things that are being modeled reside outside the metamodel hierarchy. This layer is often referred to as M1. A user object model is an instance of the UML metamodel and a service model is an instance of SML metamodel.

The metamodel hierarchy bottoms out at M0, which contains the run-time instances of model elements defined in a model. The SORCER UML model of SML is implemented in Java (SORCER API) and is used to implement all service-oriented concepts of MSF.

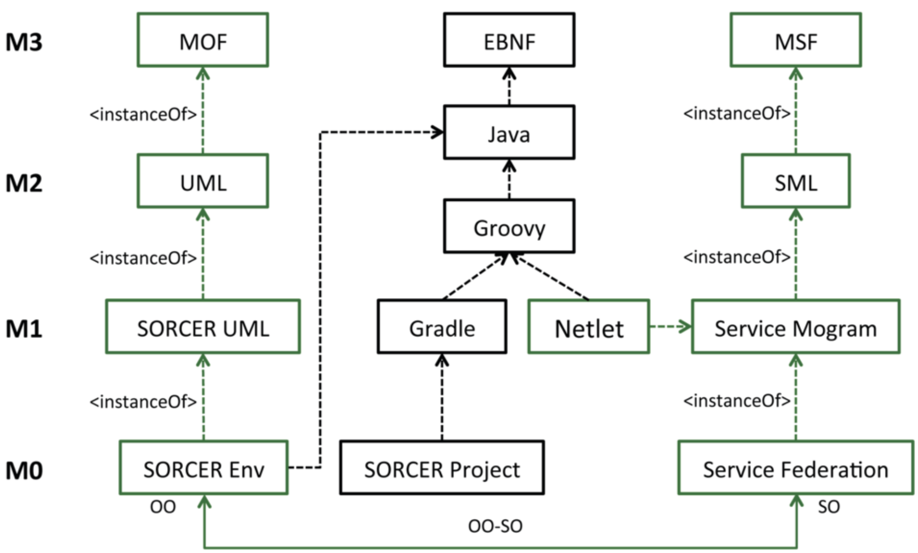

Figure 2. The UML/SML specific four-layer MOF-MSF metamodel hierarchy.

Languages can be specified by metamodeling with a great flexibility, as shown in **Figure 2** for UML and SML. They can be also specified by grammars, for example the Java language in EBNF. Interpreted SML mograms, restricted to the Groovy language syntax are called netlets so scripting is available in SORCER due to the compatibility of Groovy and Java since SML operators are implemented in Java API of the SORCER environment. The relationship OO-SO in **Figure 2** shows how object orientation in UML (backend OO provider services) meets service orientation) in SML (frontend SO macroservices.

2.2. The SORCER Platform

Computing requires a platform (runtime system) to operate. Computing platforms that allow programs to run require a processor, operating system, and programming environment with supporting tools to create and run programs. SORCER is the federated SO environment that implements FAS as defined in (10). The SORCER programming environment is based on the *Front-end as a Service* (FaaS) *architecture* with its unique *service-oriented operating system* and associated *service processor* as the collection of provider services (3). Technically, the service processor comprises Java local/remote objects implementing service types incorporated by microservices. Remote objects are deployed with dynamic small-footprint dynamic service containers called *service providers*.

Macroservices are specified in DSL called the Service Modeling Language (SML) that consists of two parts: Context Modeling Language (CML) and Exertion-Oriented Language (EOL). Macroservices expressed in imperative EOL - service programs - are called *exertions*. Macroservices expressed in declarative CML – collections of interrelated functional compositions - are called *context models*. In other words exertions are service collaborations with an explicit flow of control while models with explicit functional dependencies (no explicit control flow). A *macroservice* comprising of both context models and exertions is called a *service mogram* [8][9].

Mogram-based FaaS is a computing architecture that provides the end user the direct access to a dynamic collaboration of applications, servers, storage, databases and other resources as a backend *federation of services* (6). This architecture was introduced in the FIPER project [10] with exertion-oriented programming for creating frontend imperative services (exertions). The SORCER environment extends that approach by unifying exertion-oriented programming with context modeling (declarative programming) [11]. The SORCER Operating System (SOS) implements the FAS functions r_e, r_f, *ri*, *pr*, and *e* as defined in (10, 11, 12). Runtime federations defined by mograms that are created and managed by SOS constitute its dynamic service processor [12].

SORCER dynamically federates backend services and provides common features for network integration and location services provided by SOS [2]. An alternative to FaaS, is a common Backend as a Service (BaaS) approach that uses application programming interfaces (APIs) and software developer's kits to connect static user agents to static backend network resources. FaaS is the departure from typical application development, which requires software developers to incorporate the APIs of each backend service individually into larger backend services available to the end user. FaaS is focused on service-oriented complex adaptive models created by the end users in SML as illustrated in **Figure 3**.

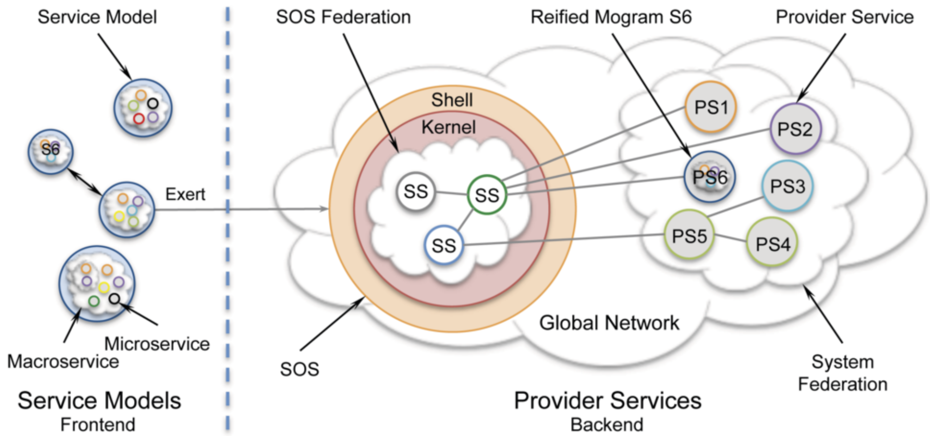

Figure 3. An exerted service model runs the system federation managed dynamically by SOS as defined by the end user. SOS binds microservices of the exerted macroservice dynamically to corresponding provider services. SOS also reifies the microservices, for example S6 as PS6, while missing services are provisioned on-demand as required if needed.

3. N^3 diagramming and Service-oriented Mogramming

Top-down and bottom-up problem solving describes two different methods of thinking: working at the top is considered strategic and declarative, while working at the bottom is tactical and imperative. How a given situation is actually perceived and processed will vary with the person, experience, and runtime environment chosen. However, the approach is to do whatever is best for managing complexity of the solution by a combination of both declarative and imperative thinking.

In declarative programming a process is expressed by a functional composition while in imperative programming is expressed by an algorithm. An algorithm is a procedure for solving a problem in the form of a self-contained step-by-step set of services (operations) to be performed with explicit control flow defined. The emphasis on explicit control flow distinguishes an imperative programming language from a declarative programming language. Service mogramming can start with either a declarative context model or an imperative exertion then can expend into the composite mogram by adding component services of either type as it fits the composition better.

The N^2 diagram [14] design structure represents the functional or physical interfaces between system elements depicted as diagonal services with connectors showing data flow between services. An expanded N^2 diagram with diagonal services that can be hierarchically organized with component diagrams representing service mograms along with multifidelity services and flow of control of exertions is called an N^3 (N-cubed) diagram [5]. An example of an N^3 diagram is depicted in **Figure 4**. It represents the following functional composition of services:

$$[g\colon e_{1,2;}\ e_{6,3}]e_{6,*}(e_{1,2}(m_x),\ m_1(e_{1,1},\ m_{y,2}),\ m_{3,1}(e_{1,1},\ e_{z,2},\ e_t)) \tag{9}$$

where $[g\colon e_{1,2;}\ e_{6,3}]$ denotes a guard for e_6 defining a loop under condition g: if g is true then $e_{1,2}$ else $e_{6,3}$. A current fidelity $e_{6,*}$ of multifidelity exertion e_6 is determined by

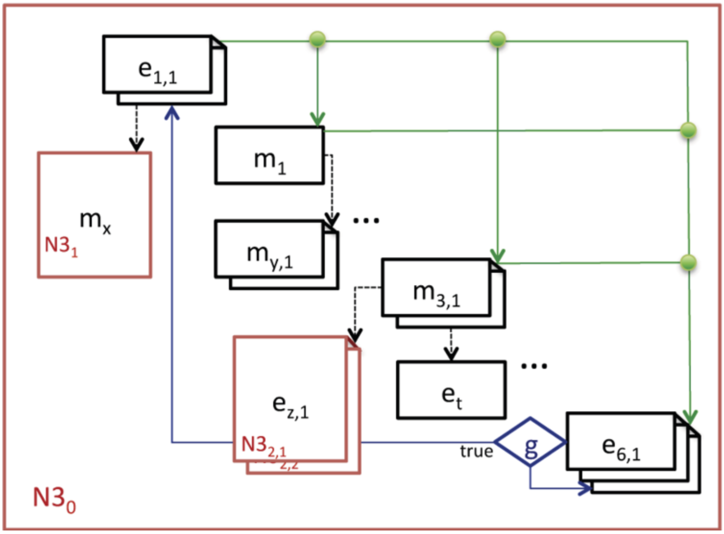

Figure 4. N^3 diagram for the composition: $[g{:}\ e_{1,2;}\ e_{6,3}]e_{6,*}(e_{1,2}(m_x),\ m_1(e_{1,1},\ m_{y,2}),\ m_{3,1}(e_{1,1},\ e_{z,2},\ e_t))$

this self-aware service at runtime. The third dimension here is represented by multifidelities of service nodes: exertion e_1, model m_3, and exertion e_6 with fidelities $e_{1,1}$ and $e_{1,2}$ for exertion e_1; $m_{3,1}$ and $m_{3,2}$ for model m_3; and $e_{6,1}$, $e_{6,2}$, and $e_{6,3}$ for exertion e_6. Additionally, each service node can be hierarchically nested with its own N^3 diagrams, for example $m_{3,1}$ depends on N^3 diagram $N3_2$, exertion $e_{1,2}$ on $N3_1$, context model m_1 on multifidelity service m_y, and service model $m_{3,2}$ on exertion e_t. The matrix crossing points (small circles) represent connectors that match outputs to relevant inputs between heterogeneous and autonomous services.

In SORCER a SO process represented by an N^3 diagram can be defined declaratively with CML as a *context model* or procedurally as an *exertion* with EOL, or with both languages at the same time as a *mogram*. Within EOL control flow exertions (branching and looping exertions) are statements whose execution results in choice being made as to which of two or more execution paths should be followed. Top-level mograms (as the root mogram in **Figure 4**) representing N^3 diagrams can be implemented either way, with declarative (CML) or imperative (EOL) mogramming semantics.

The first rule of distributed systems is don't distribute your system until you have an observable reason to do so. The concept of SORCER service signature used in models and exertions supports this rule. In a service signature first you specify your class type that implements your service type rather than the interface type of service. When you have an observable reason for system distribution then you can change the service implementation type to the interface type in signatures to have your local service modules to be remote services. Federated service-orientation is all about bringing object-orientation to the network the way local and remote objects (provider services) are alike in service collaborations specified by mograms and created by the end users. A mogram created at the frontend executes a dynamic federation at the backend.

4. Conclusions

The presented approach to ATE is based on federated service systems with multifidelity management. The SORCER net-centric reference architecture of such systems is about bringing object-orientation to the network with exchangeable local and remote provider services that are used uniformly in creating scalable service collaborations at runtime. That is consistent with the first rule of distributed systems: don't distribute your system until you have an observable reason to do so. The SORCER environment allows you to create a SO monolith (for local service federations only) and instantly distribute it step by step as needed later.

The SML modeling language of amorphous ATE systems is service provider agnostic — it is not concerned with the physical computing resources but rather with the expression of amorphous models of service federations as metamodeling abstractions (mograms) with the goal of understanding both high-fidelity physics-based modeling and emergent behavior of complex adaptive systems. SORCER is implemented in Java and provides Java API to create objects that do not correspond directly to the presented modeling conceptualizations reflected by declarative (CML) and imperative (EOL) DSLs. Java API is not the SORCER modeling language, it is used in combination with CML/EOL to implement provider services (providers) along with other languages compiled into executable codes wrapped by the providers. A mogram, created by the end users, represents a system of system instances (dynamic federations of provider services at runtime) created and morphed by the SORCER operating system.

The evolving SORCER core platform (the GitHub open source project [13]) provides front-end mogramming languages [9], Java API, and the operating system [2] that implements required realizations of FAS (10). The presented federated approach has been verified and validated in research projects at the Multidisciplinary Science and Technology Center, AFRL/WPAFB [15][16][17][18].

Acknowledgement

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Part 14

Risk Analysis and Value Engineering

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Dependability Modeling for the Failure Prognostics in Smart Manufacturing

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Abstract. The recent advances in Smart Manufacturing open opportunities in Maintenance and Management of its assets through new support strategies. This trend allows the collection of machine operation data in the shop floor, in order to interact with cyberspace computers through a communication network, therefore enabling the Cyber Physical System concept (CPS). Furthermore, the rapid advances of Information and Communications Technology (ICT) provide means to analyze Big Data, more quickly, autonomously, ubiquitously and in real time, offering information that assist in more efficient decision making in manufacturing processes. Nowadays, Prognostic and Health Management (PHM) leverages researches in the new generation of manufacturing. For this, an architecture called 5Cs, that directs the PHM implementation in CPS context is being adopted with expressive results, which allows the application of several math and/or Artificial Intelligence techniques to estimate the assets' remaining useful life. In particular, the use of Experts Systems and semantic information modeling can make it possible to represent knowledge found in the scientific literature and consolidated standards about the subject. This paper uses methodology of ontology development 101, which guides management, development and documenting of a formal taxonomy of failure prognostics. For model creation and evaluation, the Protégé suite is used, for it allows future researches to interact with the model, such as monitoring techniques and failure diagnostics in order to simulate real cases of mechanical components. This way, new possibilities for cyberspace oriented application development for industrial machine health management are revealed.

Keywords. Cyber Physical System, Prognostic and Health Management, Smart Manufacturing, Ontology Engineering, Expert Systems.

Introduction

In the new industrial generation, Cyber-Physical Systems (CPS) represent the interaction between physical spaces (sensors, actuators, mobile devices, RFID technology, embedded systems and others still) and cyberspace (computing and logical algorithms). That interaction must be ubiquitous and in real time through the internet, creating the Industrial Internet of Things (IIoT) [1], where the transit of Big Data [2] is made possible.

CPS has several applications in communication, transport, energy, infrastructure, health, public security, civil, military, robotic and disasters attendance fields. In the field of manufacturing, it improves operation process performance, monitoring and

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control, developing and implementing measurement techniques, reasoning and planning, promoting collaborative and cognitive systems, which aims increasingly the inclusion of human being with computational ambient or cyberspace [3].

Manufacturing in the CPS context requires Big Data analytics for generation useful information towards plenary understanding of systems, subsystems and their complexes interactions. According to Gao et al [4] a promising CPS application in the Smart Manufacturing context is Prognostics and Health Management (PHM), pointing out as an emerging approach of Mechanical Engineer to improve men-machine interaction through specific methods that helps to understand the machine behavior and assist to make more efficient decisions [5].

When PHM is unfold, the resulting prognosis may lead to condition monitoring in addition to events such as failure diagnostics [6]. Depending on which kind of data is needed to describe the system of interest and predict its future behavior, prognosis techniques can be classify as [4, 6, 7] physical models and data-driven approaches to estimate Remaining Useful Life (RUL) of a given asset. In particular, data-driven approaches use extracted information from historical data for establishing a relationship between nominal behavior and real time states of an operation machine, by applying either static techniques of Artificial Intelligence (AI).

On the other hand, the Health Management share refers to decision-making supplied by Prognosis through Condition-Based Maintenance (CBM), for carrying out appropriate recovery intervention or repair [4]. Between Prognostics and Health Management, the Prognostics is regarded the key-process of PHM [8]. In this context, AI techniques associated to Expert Systems (ES), based in professional knowledge representation of a particular area [9], are promising. Thereby, scientists have developed ontologies for knowledge representation, which allow interpretations of computer through taxonomies that can assist in inaccurate system function identification[10].

In Manufacturing, PHM has had good results when used in rotating elements, such as well as bearing, gears, shaft, impeller, pulley, fans, pumps, turbines, compressors, generators, electrical engine and blowers [5]. However, in the early phases of PHM development it is necessary the use to analysis techniques for dependability, which is the best way of ensure effective machine functioning in a given industrial process.

On Esmaeilian et al. [11], one of the most accepted architectures for orientating PHM implementation as CPS in the Smart Manufacturing is proposed by [12]. It details PHM into 5 levels called 5Cs: Connection, Conversion, Cyber, Cognition and Configure. The present paper further develops knowledge in data Conversion.

1. Theoretical Background

Two topics were considered essential for creating the model definition: dependability and methods for ontology engineering. Such concepts and fundamentals bring together the necessary expertise for prognostics modeling.

1.1. Dependability in factories and its attributes

According to Bukowski [13] dependability can be applied to all technology development subjects. Based in IEC 60050-192 [14] standard, dependability of an item is deemed to be the ability to perform, a function, as and when required considering attributes of availability, reliability, recoverability, maintainability and maintenance support performance.

Regarding to prognostics, dependability analysis may potentially lead to better monitoring of components in order to ensure high productivity [13].

1.2. Threats to dependability

In process of dependability acquisition, there are threats that may influence the proper life cycle functioning of manufacturing systems, either in development stage (conception) or in use stage (operation) [15]. Those threats, which may affect dependability of an item, can be considered Failure, Error or Fault.

1.2.1. Failure

Failure, according to IEC 60050-192 [14], is the loss of ability of a component to perform a required function. The failure of a component is an event that results in a system fault. According to Avižienis et al. [16], all failures that may affect a system during its life are classified as: creation, boundaries, cause, dimension, objective, intent, capability and persistence. The present paper discusses failure that can happen in a mechanical component (physical failures), resulting from a human action (human-made failures).

1.2.2. Fault

Fault, according to IEC 60050-192 [14], is the incapacity of a system to perform its required functions due the functioning deviation of an internal state. Fault in a system results from a component failure in its own system or a disability in an earlier stage of its life cycle, such as specification, design, manufacture or maintenance.
In the present study, faults that may be detected, classified in the detectability category, according to events through which the fault presence becomes evident [14].

1.2.3. Error

Error, according to IEC 60050-192 [14], is the discrepancy between a computed, observed or measured value or condition, and the true, specified or theoretically correct value or condition. Therefore, a procedure that guides the correct choice of technique, mechanism or device used to monitor the component behavior is necessary.

1.3. Means to attain dependability

The means to achieve dependability, may be categorized as: Failure Prevention, Failure Tolerance, Failure Removal and Failure Prognostics [16]. Failure prevention and failure tolerance aim to provide the ability to deliver an operation that can be trusted, while failure removal and failure prognostics aim to reach confidence in that ability by justifying that the functional and the dependability specifications are adequate and that the system is likely to meet them.

Thereby, the present work aims focus in failure prognostics as a way to estimate RUL in a given mechanical component.

1.4. Dependability analysis techniques

According to IEC 60300-3-1 [17], there are several techniques that assist in failure prognostics, such as: Failure Tree Analysis (FTA), Failure Mode, Effects and Criticality Analysis (FMEA), Markov analysis, Hazard and Operability study (HAZOP), Petri Net (PN) and Reliability Block Diagrams (RBD) [18].

Vogl, Weiss and Donmez [19] suggest that dependability techniques may be classifies into top-down and button-up approaches. On Sanislav et al. [18], they can be divided according to its quantitative and qualitative purpose. In addition, the dependability analysis techniques that can assist in the extraction of cause-effect relationship might be classified into deductive or inductive.

Those authors highlight FMEA uses for dependability analysis as it is: (a) a qualitative technique for identifying component failure modes; and (b) inductive, because it aims the prognostics of potential failures effects from known causes and for being a bottom-up approach, which first identifies failure modes in components, then establishes its effects.

1.4.1. Failure Mode and Effect Analysis

FMEA is a powerful technique used by engineers and reliability analysts to identify functions and components in which failure will lead to unwanted results, such as production loss, damage or even accidents. The main FMEA purpose is to find out and prioritize failure modes potentials through Risk Priority Number (RPN) estimate that represent a negative effect on the system and its proper functioning [20].

FMEA added to Criticality Analyses is called FMECA. Nowadays, the scientific literature considers FMECA and FMEA synonyms, since both identify failure modes, their effects, causes and prioritize its relevance through RPN, which is the multiplication of obtained values in Severity, Occurrence and Detection [20].

The FMEA development must gather technical knowledge, such as standards and scientific articles, and this knowledge can be modeled through ontology for several applications. Some FMEA applications in manufacture processes using ontology are present in Zhao and Zhu [21].

In order to find the RPN, it is important to standardize scoring parameters. Thereby, the SAE J1739 standard [22] establishes parameters to: specify severity of a given failure mode, occurrence for a cause or source cause, and finally presenting a classification scale for the probability of failure or cause mode, for detection and/or prevention of a cause occurrence in an existing control or system scheduling.

2. Ontology engineering

According to Aljumaili et al. [23], the term ontology refers to the philosophy that concerns the nature and reality structure. Therefore, ontology engineering focuses on nature and structure of things, regardless of its actual existence. In computing, specifically in the AI area, ontology building is the technique that represents the formal knowledge of a specific interest domain that is shared by a group of people. In some manufacturing solutions, the interopeability desired for operating data, used for strategic decision-making can be ruled by specific standards through ontology uses.

When creating an ontology, it is important to adopt a methodology for arranging and defining the construction stages. According to Bautista-Zambrana [24], methodologies for building ontologies involve a set of activities such as, conceptualisation, formalization, implementation and maintenance. Some highlighted methodologies are: Uschold and King's, METHONTOLOGY, On-To-Knowledge, TOVE, OntoClean, DILIGENT, Ontology Development 101 and DOGMA.

Besides of methodologies, ontology engineering requires tools that support all development activities. Commercial tools, such as TopBraid and OntoStudio are available, as well as free options, such as OntoEdit, Hozo and Protégé. Among those tools, are highlighted those that are not owned, and which have plug-in extensibility, along with import and export capabilities in XML (S), OWL, RDF (S) and Excel formats, as well as graphical views. The Protégé editor stands out for meeting those requirements.

Protégé is the most used tool for editing ontologies in the scientific world [25, 26]. It is developed and maintained by Stanford University, which is also aligned with Ontology Development 101. The present work uses Protégé as a modeling tool and Ontology Development 101 as the construction approach, as proposed by Natalya and Deborah [27], and illustrated in Figure 1.

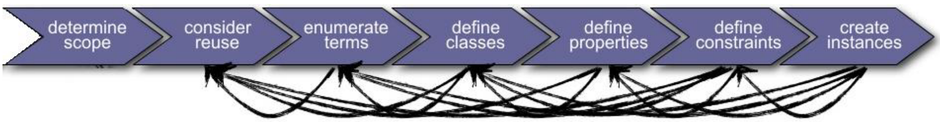

Figure 1. Stages suggested according to methodology 101, adapted from [27].

3. Case study

3.1. Failures in mechanical components

The component used in the case study is a bearing that has the function to reduce wear on the operating shaft of a centrifugal ventilator. Part of the interaction of its failure modes are represented by an ontology that formalizes its dependability analysis through FMEA technique. Table 1 highlights the factors to be modeled for the failure mode "bearing seized", having the "overheat" effect, rated severity "8" caused by "insufficient lubricant", rated occurrence "5" with "training" as a preventive control, "vibration analysis" as detection control and rated detection "8". Ontology prognostics is modeled considering those characteristics in terms of having obtained the highest RPN, which is 320.

Table 1. FMEA partial for failure prognostics modeling.

Item/ Function	Failure Mode	Failure Effect	SEV	Possible Cause	OCC	Current Control: Prevent	Current Control: Detect	DET	RPN
Bearing / Reduce friction of the rotating shaft	Bearing seized	Overheat	8	Incorrect type of lubricant	1	-	-	8	64
				wrong procedure of lubrication	1	-	-	10	80
				insufficient lubricant	5	Training	Vibration Analysis	8	320

I. Determine scope

The ontology domin is failure prognostics, which is a way to achieve dependability in manufacturing machines. An ontology can be built to identify failure modes in the mechanical component, "bearing". An important aspect when identifying failure modes is that there is a dependency of threat types that will rank their nature for future analysis. This ontology called OntoProg, maintained by the research group GECVP from UTFPR, can be used in various types of industrial process machinery.

II. Consider reuse

With the establishment of the scope of ontology, it could be used as a reference to ontologies developed in [18].

III. Enumerate terms

Several terms were considered for this ontology related to the threats of dependability as the FMEA technique, such as cause, effect, occurrence, severity, failure, defect, error, etc. For this step to be standardized the terms and their meanings were collected from consolidated standards and scientific articles, related to equipment dependability.

IV. Define Classes

DependabilityAnalysis is the main class of the proposed ontology and contains subclass FailurePrognostics as a way of reaching prognostics, which in turn has subclasses Threats and FMEA. Each of these classes has its own subclasses. For example, subclass Threats has subclasses: Failure, Fault and Error. The subordination relationship between class and subclass is a 'subClassOf' axiom type. The 'DisjointWith' axiom type relationship exists between classes, so that the instance contained in it can not be an instance of more than one of the involved classes. For example, Failure is DisjointWith Fault and Error. So Fault is automatically DisjointWith Failure and Error and Error is DisjointWith Fault and Failure. The class hierarchy is presented in Figure 2.

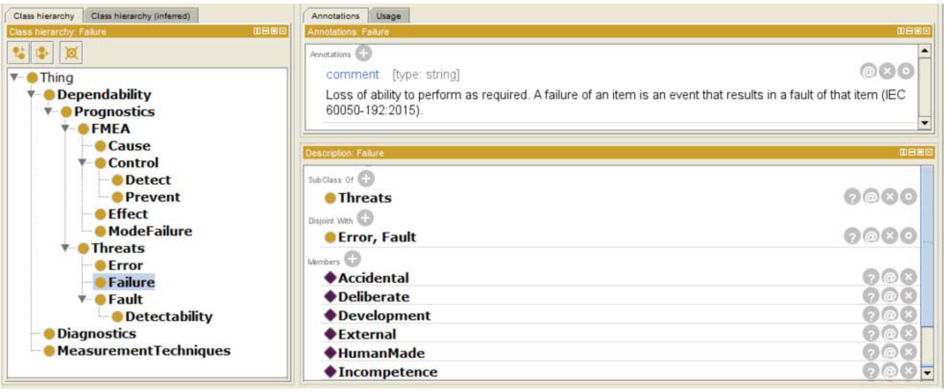

Figure 2. Classes hierarchy in OntoProg ontology.

V. Define properties

There are three types of properties: ‘Object Property’, that establishes a relationship between two ontology classes, ‘Data Property’, which lists the classes with different data types and ‘Annotation Properties’, which enables adding information to classes, instances (objects) and even other types of properties. Below are detailed properties and their corresponding Ranges. Figure 3 shows properties of the classes in Protégé: Object Properties: hasCause (Cause), hasControl (Control), hasEffect (Effect), hasMode (ModeFailure), isResultedOf (Failure) and isCausedBy (Failure); Data Property – hasDetection (integer), hasOccurence (integer), hasSeverity (integer).

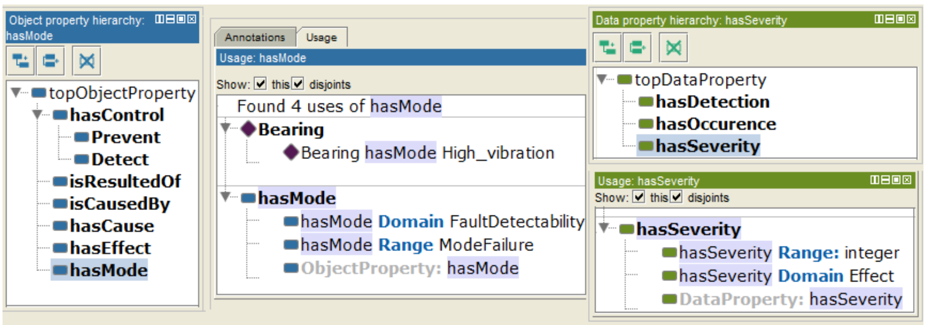

Figure 3. Proprieties in OntoProg.

VI. Define constraints

At this stage transitive properties are defined. For example, if instance "Bearing" hasCaused an instance of the class Cause and this cause isResultOf an instance of Failure class then the instance "Bearing" isResultOf an instance of the class Failure. Therefore, inferences of type the "Bearing" also isResultedOf of Accidental, NonDeliberate Incompetence and NonMalicious failures can be performed, as shown in Figure 4.

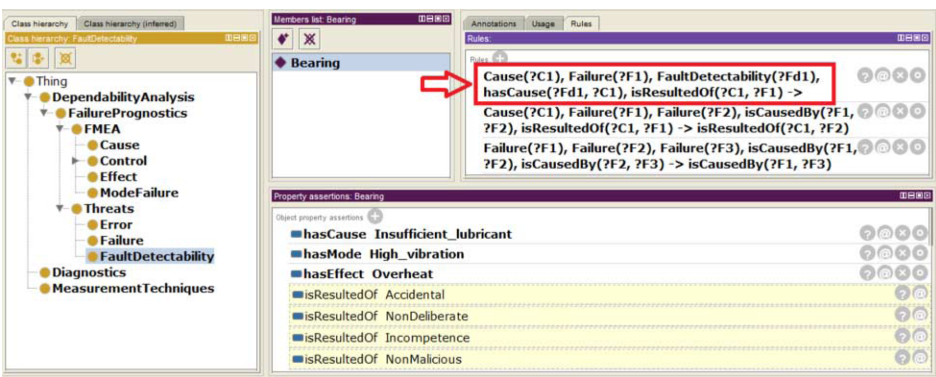

Figure 4. Transitive restrictions for generating instances in in OntoProg.

VII. Create instances

Instances are designed to: Cause, Control, Effect, Modefailure, Failure and FaultDetectability. Figure 5 presents instances of Failure Class. In this connection, it can be seen that the purple color arrows refer to subClassOf property, blue arrows are Types properties, and orange dashed arrows are the isCausedBy object properties.

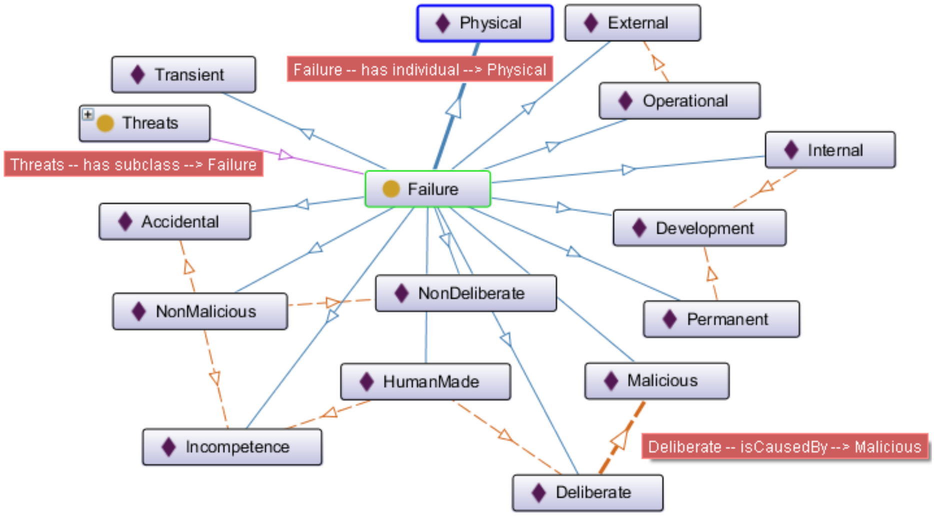

Figure 5. Instances of Class Failure in OntoProg ontology.

4. Testing and Results

The proposed model of dependability analysis can be interpreted, accessed and updated in real time by cyberspace for some applications in failure prognostics. For this, the model must be tested first. This is possible with SPARQL that performs query ontology language (SPARQL Protocol and RDF Query Language) for being the most used form [28].

Protégé provides an editor to create SPARQL queries. In it, it uses utfpr prefix to connect with the dependability analysis model called untitle-ontology-111, Figure 6.

That way, the query in the SPARQL OntoProg ontology can be used to find, for example, within class Failure, all X instances that have isCausedBy Y property, as shown in Figure 6. These results can be used by software applications through APIs, such as Jena Semantic Web Toolkit and Jena Fuseki.

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX utfpr: <http://www.semanticweb.org/david/ontologies
          /2016/3/untitled-ontology-111#>

SELECT ?X ?Y
       WHERE { ?X utfpr:isCausedBy ?Y }
```

X	Y
Operational	External
NonMalicious	Incompetence
NonMalicious	NonDeliberate
Permanent	Development
HumanMade	Deliberate
Deliberate	Malicious
NonMalicious	Accidental
HumanMade	Incompetence
Internal	Development

Execute

Figure 6. Failure Class instances in Protégé.

5. Final remarks and future work

This paper deals with CPS scientific challenges related to the development of new PHM models , including threat identificating methods (Failure, Fault and Error). In addition, this article seeks to establish the theoretical foundations for dependability modeling of failure prognostics in the CPS context. In this regard, the article proposes a methodology to ensure the PHM dependability, by suggesting a model to adapt in a dynamic and evolving context in cyberspace. The methodology uses the FMEA technique as dependability analysis and Ontology Development 101, built upon seven stages.

The model is implemented in Protégé and all the necessary steps for their generation were detailed. In addition, tests were carried out through queries in SPARQL, which show that the model can be used by other applications in the CPS context, highlighting its scalability and usability.

The model integration methods for determining failure diagnostics and condition monitoring techniques within the PHM context will be subject of future work.

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Guidelines for Development of Risk Identification Expert System for Product Design

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Abstract. Product development projects present numerous uncertainties that lead to risks, especially in the design phase of the product which involves qualitative, abstract and insufficient information about the problem and the product that is the object of development. Risk management in product design consists of a formal and systematic management process which aims to identify, analyze, treat, monitor and control risks related to their activities and tools. Expert system is an artificial intelligence based system that simulates the judgment and behavior of a human with expert knowledge and experience in a particular field. It contains a knowledge base system with accumulated experience and a set of rules. This article aims to provide guidelines for the development of an expert system for the risk identification phase in product design. It also approaches a risk management methodology with focus on the risk identification that has been already developed and assisted to product design. This paper concludes with a partial and general conceptual vision of the expert system to be developed.

Keywords. Risk identification, expert system, product design.

Introduction

The growing area of innovative products demands complex situations for the development team that faces lots of uncertainties that consist of a group of unknown events related to the future, which can include favorable or unfavorable events. The events that originate favorable results are called opportunities and the ones that originate unfavorable results are called risks [1].

Risk management is defined as a formal and systematic method of management that includes identifying, analyzing and responding to the risks of the project during its life cycle, in order to achieve the project objectives [1].

The project team members are involved in the risk management processes, because of their qualification and specific knowledge to identify, analyze, respond to and control the risks. Thus, they are also one of the most important resources for reducing risks due to their competence and experience [2]. Expert system is a computer program that simulates the judgement and behavior of a human with specific

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knowledge and experience in a particular field. It contains a knowledge base containing accumulated experience and a set of rules [2].

The purpose of this paper is to present guidelines for the conception of a risk identification using expert system for the product design process. Therefore, a methodology for the integrated management of technical and managerial risks related to the product design process is presented. Then, an overview about the expert system structure and applications and finally, guidelines for risk identification using expert system for the product design

1. Methodology for the integrated management of technical and managerial risks in the product design process

As projects are about doing something new, they are about change. Change introduces uncertainty and uncertainty is risk. Risk Management (RM) is about the steps you take in a systematic way that will enable to identify, assess, response and control risk. Risk management is the identification, assessment, and prioritization of risks (defined in ISO 31000 as the effect of uncertainty on objectives) followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events [3] or to maximize the realization of opportunities. Risk management's objective is to assure uncertainty does not deflect the endeavor from the business goals [4]. An exceptional management of risks results in better decision-making, better understanding of the risks, comprehension in how it affects the project and the responses to be taken in the event of risk.

The purpose methodology presents phases, activities and methods for the integrated management of technical and managerial risks in the product design process. There are three phases in the risk planning: Identification of technical and managerial risks; integrate analysis of technical and managerial risks; and treatment of technical and managerial risks. The planning project is updated in terms of scope, time, cost and quality, as the activities of the design product are used to input information. The main output information of each phase are, respectively, list of technical and managerial risks; inflect of technical risks in the managerial risks; and implementation of action plan for the treatment of technical and managerial risks.

In order to present better comprehension of the methodology, a scope of the integrated management of technical and managerial risks is presented in Figure 1.

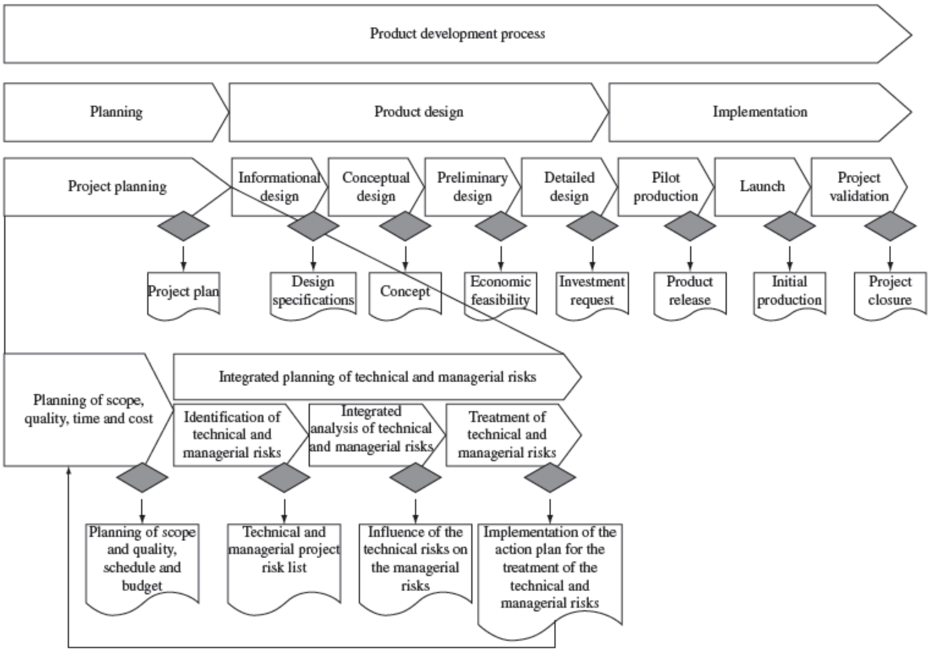

Figure 1. Scope of the methodology for the integrated management of technical and managerial risks related to the product design process [4].

1.1. Integrated planning of technical and managerial risks

As part of the planning of scope, quality, time and cost, the integrated planning of technical and managerial risks include the identification of the risks.

1.2. Definition of technical and managerial risks

The methodology used in this paper consists of the identification of the technical and managerial risks from the categories defined in Tables 1 and 2.

Table 1. Technical risk categories related to the product design process [4].

Technical risk categories	Definition
Input risks	Risks arising from the input information to be transformed by the product design activities.
Domain risks	Risks relating to the project team and the product clients/customers in terms of knowledge domains required in the product design activities.
Mechanism risks	Risks derived from the methods, tools and other resources to be used in the execution of the activity.
Output risks	Risks arising from the output information or physical objects to be transformed by the product design

Table 2. Risk management categories [4].

Risk management categories	Definition
Scope risks	Risks related to the product and project scope.
Time risks	Risks associated with the product design process and the project schedule.
Cost risks	Risks related to the project costs.
Quality risks	Risks associated with the desired quality

1.3. Identification of technical and managerial risks

The identification of technical and managerial risks are based on the risk identification. To sustain the technical risk identification, investigative questions needs to be respond by the team project of the product design as presented in Figure 2.

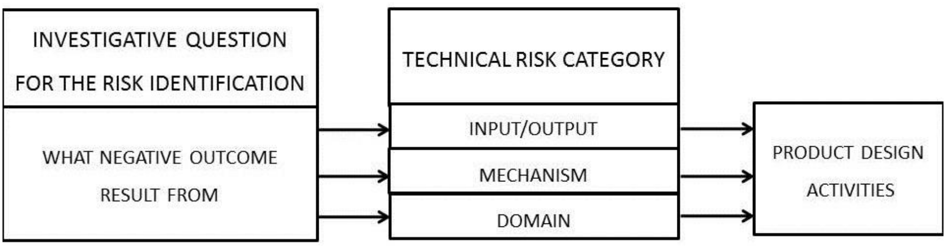

Figure 2. Formularization of investigative questions for the technical risk identification [4].

A structure of investigative questions similar to the one suggested for the technical risks is proposed for the identification of the scope, time, cost and quality of managerial risks. The following elements must be specified for each risk identified: definition, cause, impact, responsibility, estimated date of occurrence and domains involved. Risks from the investigative questions outline the technical and managerial project risk list.

1.4. Prioritizing the technical and managerial risks identified

The number of identified risks in product development projects can be high, given the innumerable uncertainties. Therefore, since risks have different characteristics, it is necessary to prioritize these risks. The calculation of the Risk Importance Weighting (RIW) is classified by six characteristics.

The first characteristic (Figure 3) to be defined is the probability of occurrence for each technical and managerial risk identified. Then, the project team must allocate one value to the severity of each impact of the identified risks. Considering that generally risks involve more than one impact, the average severity (arithmetic mean) of each value needs to be calculated for the characteristic 2 . These average values must then be classified according to the scale presented in Table 3 [1].

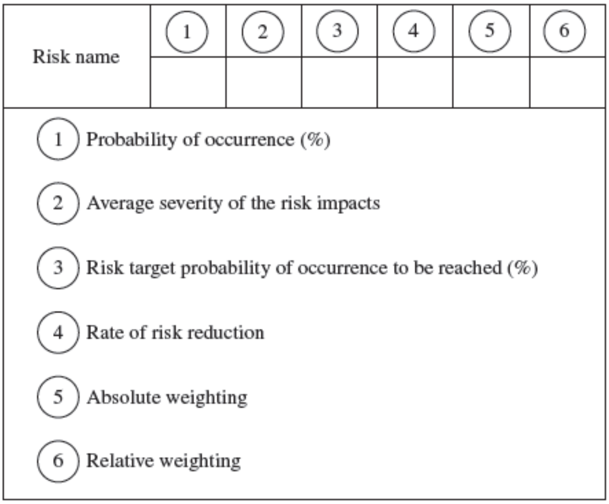

Figure 3. Elements for the calculation of the risk importance weighting [4].

Table 3. Scale for the average severity of the impacts [1].

Interval	Severity of the total impact
[0.1,0.3)	Very low
[0.3,0.5)	Low
[0.5,0.7)	Medium
[0.7,0.9)	High
≥ 0.9	Very high

For characteristic 3, is necessary to define the target probability of occurrence to be reached. This characteristic involves defining the risk tolerance, the maximum value that the project team can accept for the risk probability of occurrence.

In this regard, the project team must define the target probability of occurrence to be reached within an interval from 0 to 1.Values close to zero means that the project team desires that the risk is eliminated before it happens. Values approaching 1 mean that is a negligible risk in the project team's opinion.

Based on the definition of characteristics 2 and 3, it is possible to calculate the rate of risk reduction of characteristic 4, which is the division of the former by the latter.

Finally, based on the four risk characteristics defined previously, the absolute weighting and the relative weighting for each risk are calculated. The risk absolute weighting is obtained by the multiplication of the average severity of its impact by its rate of reduction. For the calculation of each risk relative weighting, it is necessary to divide the risk absolute weighting by the sum of all technical and managerial risk absolute weightings.

After the calculation of each risk relative weighting, the values are ranked to show the order of importance. A list of the technical and managerial risks by priority order is obtained.

The identification of technical and managerial risks phase for the product design permits the definition of a list of technical and managerial risks based on uncertainty input, domain, mechanism and output presented in the main activities of product design and in the uncertainty of scope, time, cost and quality of project, prioritizing the risks. Therefore, the scope team project is capable of knowing the nature of their projects and the management of risks.

2. Expert System

Expert system (ES) can be defined as artificial intelligence based system that converts the knowledge of an expert in a specific subject into a software code. Expert systems are systems which are capable of offering solutions to specific problems in a given domain or which are able to give advice, both in a way and at a level comparable to that of experts in the field [3].

Expert system is a computer program that simulates the judgment and behavior of a human that has expert knowledge and experience in a particular field. It contains a knowledge base containing accumulated experience and a set of rules [5].

2.1. Structure of an Expert System

An ES is typically made up of at least three parts: a knowledge base, an inference engine and a working memory [6], as showed in Figure 4.

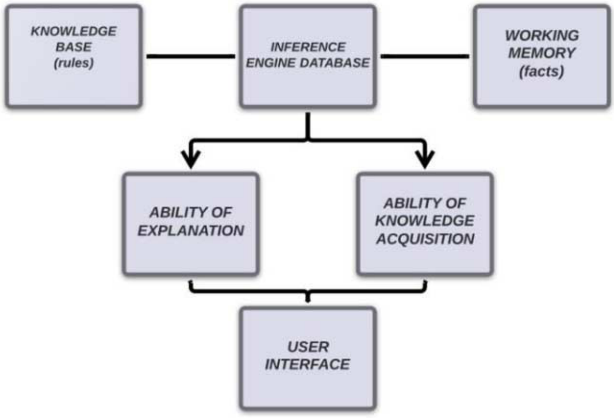

Figure 4. Expert System Structure Flowchart [7].

- Knowledge base is a representation of heuristic and factual information, often in the form of facts, assertions and deduction rules [8]. The structure is represented in IF-THEN rules, concepts and nets for representing knowledge acquired by the expert domain use in problem solving.

- Inference engine is a mechanism, playing the role of an interpreter that applies the knowledge as represented in a suitable way to achieve results [8]. It uses the domain knowledge as a data base together with acquired information given by the user stored in the working memory to provide an expert solution.
- Working memory is used to store temporary information knowledge, called FACTS, gained from the user of the system and relate it to data base.
- Ability of explanation clarifies the reasons found by the expert system.
- Ability of knowledge acquisition provides the user an automatic way to put knowledge into the expert system.
- Interface is the communication mechanism between the user and the expert system. Allows the user to express the problem in a human language.

3. Expert System for Risk Analysis

Building expert systems for specific application domains has even become a separate subject known as knowledge engineering [3]. The coverage area of knowledge that expert system can be used makes it an important area of study and application. Technology applied in projects has become a powerful tool for companies to achieve its primary goals.

Complexity of risk analysis requires a good technology in order to define, quantify, decompose, assess, control and response the decision making over the risks. Language used in expert systems helps to deal with risks implications and make it easier for all parties to use it. The efficiency and comprehensiveness of using expert system have grown in the field of risk analysis.

3.1. Risk Expert System in Management Area

Risk has become a specific area of study and also it's characterized for having an exponential growth of weight in different areas and organizations in general. That provides an opportunity to introduce an expert system with empirical and logical structure to analyze risks in any kind of assessment, projects and business companies. Some studies have proved the possibility of this application.

An article about a software project named RiskExpert was published [9]. An ES tool that can be used by management for analyzing metrics data predicting future results based on past trends and expert knowledge. Project groupings are determined by the systems administrator, and new groups can be created at any time subject authorization. Rules are categorized such as analysis, explanation, advice, and aggregation. The expert advice generated by RiskExpert from metric data analysis can greatly aid in reducing various risk involved in a software project life cycle, such as cost overruns and schedule delays.

An Expert System prototype to be used in construction risk management that favor risk identification by providing a list of most significant uncertainty factors and their description was proposed by [10]. The user select those factors related to the given project. Each of it is further divided into sub-elements then provides the user added details. The system gives suggestions for risk allocation and risk transfer to another party and proposes specific advice to minimize risks and their consequences.

Expert-Risk is a prototype developed to function at two levels: Expert system for risk management planning before the start of a project and during project operation.

[11] Designed an expert system risk assessment cycle of an enterprise, based on the steps of a management system, by risk modeling and treatment according to the data of the industrial environment. Risk assessment was done by using semi-quantitative methods for a qualitative risk assessment which is then evaluated by giving scores. The method avoids the accumulation of errors that can occur in the qualitative method and the complexity of data that are necessary in the quantitative evaluation. It was concluded that communication and control are important actions in the development, optimization and stabilization of the company.

A decision-making framework that uses a fuzzy expert system in portfolio management for dealing with the uncertainty of a New Product Development (NPD) is presented by [12]. The fuzzy inference-based portfolio framework was designed to be an effective decision-making process that can evaluate numerous NPD projects with limited resources and make a sound selection of the optimum set of products. The portfolio framework consists four phases where target goals are set, projects are then evaluated by the portfolio expert system, fuzzy inference is used to score model in a matrix. The fuzzy inference model is called XpertRule, where the numerical results of the matrix evaluation are converted into fuzzy linguistic variables, then converted into categories. The suggested expert system-based approach focuses more on evaluation process than evaluation criteria and decision-making rules.

The structure of an expert system and its application area gives knowledge to recognize its importance and the relations between risks and expert system. The expert system has a structure that improves on processing the data of an empiric knowledge and offering solutions to specific problems in a given domain such as risks.

4. Guidelines for Development of Risks Identification Expert System for the Product Design

Based on the methodology for the integrated management of technical and managerial risks to the product design process and the review of risk expert system, guidelines are presented to be used in the proposition of a risk identification expert system for the product design in order to format a functional structure of the risk identification in expert system :

- For the risk identification, consider the risk management categories proposed by [4];
- For the risk characterization, consider the elements for the calculation of the RIW proposed by [4];
- Issued the list of technical and management risks in order of priority
- Use knowledge of the project team members to identify and characterize the technical and managerial risks
- Explain how to assign values for the calculation of the RIW Proposed by [4];
- Configure the system modules to perform the functions set and allow the expansion phases analysis and treatment of risks

- Store information about the risks to constitute a database for its management

Based on the guidelines above, a functional structure of the expert system to be developed is proposed, with its main functions and relationships.

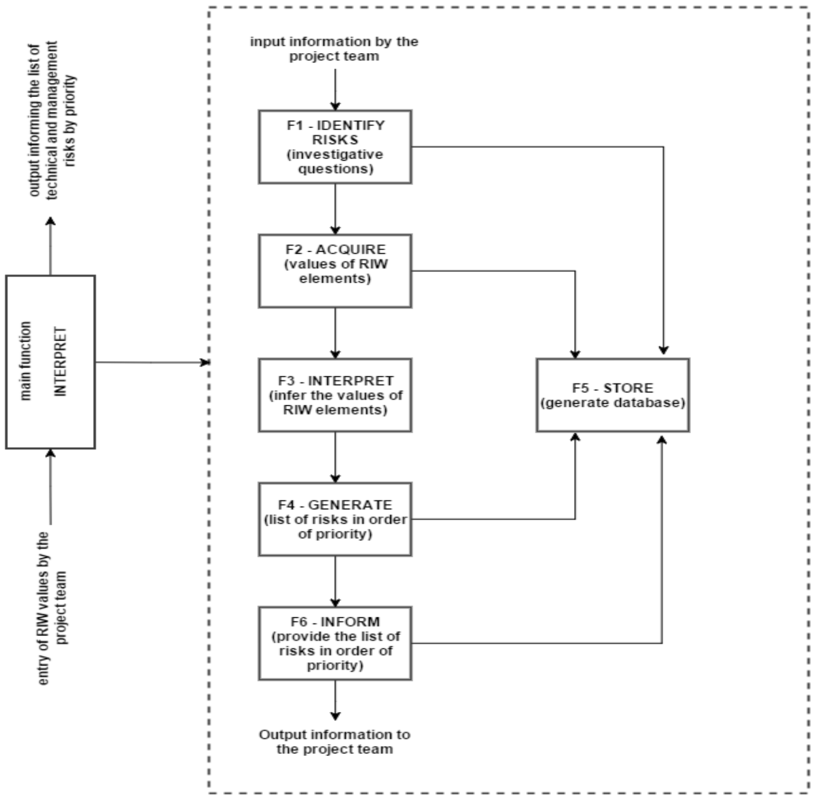

Figure 5. Functional Structure of the Risk Identification Expert System.

The project team provides the analysis that the expert system identifies the technical and managerial risks, characterize them and issue a list of technical and management risks by priority as shown in Figure 5. To execute the main functions the expert system acquires the values of the elements for the calculation of RIW, interpret data inferring on the knowledge of the project team, generate the list of technical and management risks in order of priority, store the information generated by the acquisition and interpret and generate again, function performed each time a value is entered or modified.

5. Conclusions

This article presented an overview of the methodology for the integrated management of technical and managerial risks related to product design followed by the identification and characterization of the technical and managerial risks detailed in terms of tools. The investigative questions and the risks highlighted in the risk identification phase stimulate the project team to reflect on potential risks in the main activities of the product design process and the project risks of scope, time, cost and quality. The main output of this phase is the priority list of technical and managerial project risks.

Likewise, the article presents a brief review of the concept and structure of an expert system and articles already developed in the literature focused on risk management through expert system. It can be concluded that the articles cited, despite providing a basic direction, are not directed to risk management in product design as shown in this article. The gathering of the methodology for the integrated management of technical and managerial risks related to the product design process together with the functional structure of the risk identification in expert system can be an effective tool to be applied in any product design process.

In this regard, the next steps of this research aims to determine the computational tools to be used in the SE; define how the knowledge of experts will be entered in the database; configure the expert system modules to perform the functions set and establish the number of versions required for the system.

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An Exploratory Study of the Implementation Process of the FMEA Method in the Product Development Process of Companies

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Abstract. This study aims to evidence problematic aspects for the implantation of FMEA method (*Failure Mode and Effects Analysis*) in the Products Development Process (PDP) of industries. The technical procedures used were literature review and action research, besides the implantation of FMEA method in a big company of metal-mechanic industry. The research offers a synthesis of various experiences about the implantation of design methods in the industry, rescuing values of human wisdom that previously had not received great attention. The main result of this research is an implantation process of FMEA method, consisting of main stages, results and recommendations to help companies to use the methods for technological innovation and increase the competitiveness.

Keywords. Products development process; Design methods; Implantation; Improvement

Introduction

According to [1] and [2], in the engineering area, various methods have being created to support the different stages of the Product Development Process aiming cost reduction, reducing time to market and improved quality. To [3] and [4], the application of design methods helped in developing professionals' skills in product development and creating competitive advantages for companies.

However, the studies by [5] and [6], in the Brazilian corporate landscape, there are few companies that have a formal PDP, systematized by methods, techniques and tools to develop their products, as the procedures used in conducting the corporate product development process are based, in most cases, in experiences of professionals from each company. [2] conducted an international comparison between surveys conducted in the UK by [7] and New Zealand by [8], regarding the use of design methods by the companies, according to Figure 1.

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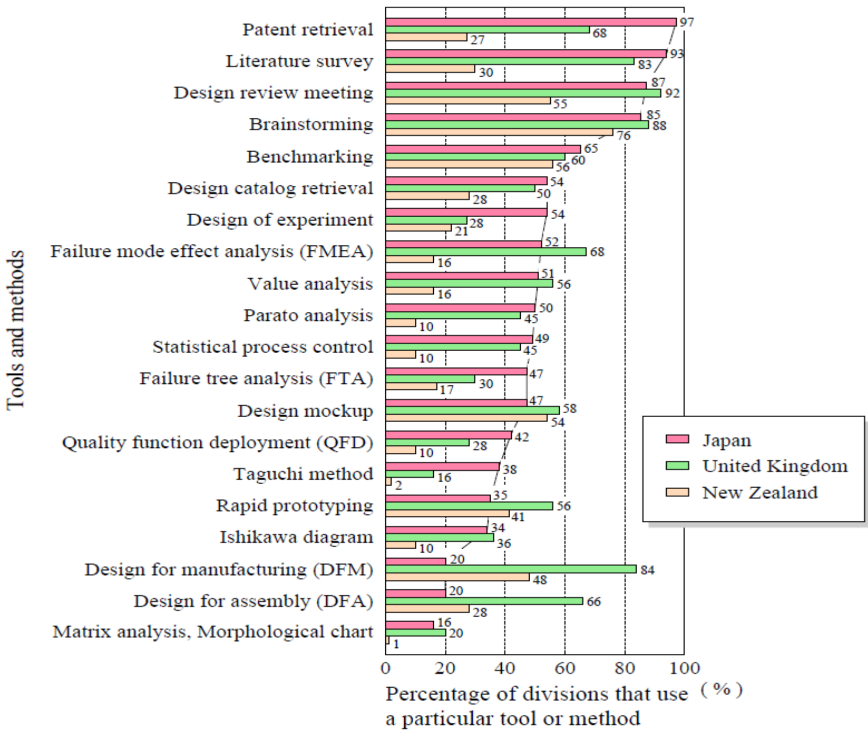


Figure 1. Comparison of utilization of tools and methods among Japan, United Kingdom and New Zealand [2].

A similar study was carried [9], which revealed that German industry does not use the methods intensively but only occasionally. Among the methods evaluated in the research, FMEA method is one of the lowest percentage of regular use (approximately 18% regularly use, 45% use occasionally and 27% not use).

A study developed by [5] with thirty medium-size and large companies, located in the south of Brazil from the metal-mechanic, electrical equipment, communications, transport equipment, as well as plastic products and non-metallic industries, revealed the methods that companies use, the methods they know but don't use and the methods that they don't know. The research shows that most companies have not learned about design methods and their potential, in other words, the usage of the methods is relatively small, as seen in the Figure 2.

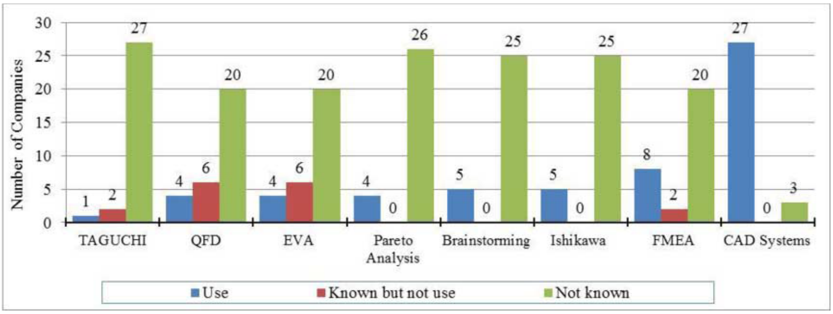


Figure 2. Usability of methods by Brazilian companies, adapted from [5].

Therefore, according to the surveys conducted in companies from Japan, the United Kingdom, New Zealand, Germany and Brazil, as shown above, the percentage of companies using the regular form of design methods is relatively low. Based on research, we note that the FMEA method, in particular, has a low percentage of use on a regular basis in the industry.

Analyzing the importance of the methods for technological innovation and increase of companies competitiveness, even if design FMEA is well known and used at many companies the implementation process is not fully explored, this paper presents a study about the implementation of FMEA method in industries, aiming to generate a set of decision support principles and recommendations for deployment of such resources in the industry.

1. Theoretical Framework

1.1. Selection and implementation of design methods

Source [10] reports that the ability to reason and systematic operation are essential for the application of design methods with success in the industry. According to source [11] for the acceptance of methods or design methods to occur, it is necessary for two barriers to be overcome: acceptance of the method and its successful use. Therefore, it is necessary that managers and projects coordinators are convinced that the use of the method will benefit the company's performance. For [9], a basic prerequisite for application of design methods in the industry is the technical knowledge (know-how) to use them in different situations.

In this context, some researchers have developed models for structuring this content in order to facilitate the use of methods to support product development. A brief comparison between the developed models is shown in the Table 1.

Table 1. Comparison between selection models and implementation of design methods.

Model	[12] Munich Model of Methods	[13] Process-oriented Method Model	[14] Assessment and Selection of Product Development Tools
How is the design method selected?	By analysis of the company’s PDP	By analysis of the company’s PDP	By the needs of each project
Is the design method adapted to use? How?	Yes, by breaking down the method in steps	Yes, by breaking down the method in steps	No, by selecting the application of the method.
What are the main steps of the model?	Selection, Adaptation and Application.	Inputs, Sequences of actions and Outputs.	Understand the problem, set objectives, find solutions and evaluate solutions.
What are the design team's requirements?	Knowledge of the method	Ability to use the method and infrastructure.	Knowledge of the method, intuition and experience.

One can notice that the Munich Model of Methods and the Process-oriented Method Model provide the method content in a modular and structured way, so that there is an adaptation of the design method. While the Assessment and Selection of Product Development Tools aims to identify the various activities that make up a typical decision-making process for acquiring development tools.

1.2. FMEA – Failure Mode and Effects Analysis

According to ABNT (Brazilian Technical Standards Association), the FMEA means Failure Mode and Effects Analysis and is a qualitative method of reliability analysis which involves the study of failure modes that may exist for each item, and determining the effects of each failure mode over the other items and the set specific function [15]. FMEA compared to FTA method (Fault Tree Analysis) is a method that analyzes the low failure up (bottom up), or acts to predict a failure; while the FTA analyzes the fault from above (top-down), or when it has already occurred [16].

For sources [16], [17] and [18] the key success factor for efficient deployment and effective implementation of FMEA in the industry, is the domain knowledge of the following concepts:

- **Failure Mode**: is the shape of the defect, the manner in which the defect is present, how the item (component) fails or ceases to provide the desired results or expected, how the item physically failure. The failure may be structural (physical) or functional (related to the item's function).
- **Effect**: is the result produced by an action or an agent, called question in relation to this result, the consequence of failure, end destination. The effect is like failure is perceived at the system level, as it manifests itself and how it is seen by the customer.
- **Cause**: what determines the existence of a thing; what determines an event; agent, cause, reason; origin principle. The causes of the failure mode are the reasons that led the failure to occur and may be in the vicinity of components, environmental factors, human error or component itself.
- **Risk Priority Number (RPN)** is the result of the Severity (of the event), Probability (of the event occurring) and Detection (Probability that the event would not be detected before the user was aware of it).

The FMEA can be used with other methods. Among them, according [18] include: Failure Tree Analysis (FTA), diagram Ishikawa, Benchmarking, Pareto Chart, Checklist, Histogram and Evaluation Matrix.

2. Material and methods

Based on the concepts of source [19], this study was classified as applied research, as it aimed to apply knowledge to product development in the industry. About the approach, it was classified as qualitative research because it used interviews, document examinations and presents a descriptive character.

The technical procedures used were: Literature Reviw, related to the state of the art about PDP and design methods and action research, support for the implementation of design methods in the company. The flow of execution of methodological procedures and their activities are represented in the Figure 3.

Figure 3. Methodological research procedures.

According to source [19], the action research is a very flexible method and does not require a chronological ordering of its phases. This research method was selected due to the effective participation of members involved in the process and be a method widely used by the industry. For action research, a large manufacturing company from the metal-mechanic sector was selected, named in the study in order to preserve its identity, as Action Research Company (represented by the letters ARC).

3. Implementation Process of FMEA method

The term implementation process was used to demonstrate the planning, execution, results, evaluation, improvement and standardization of the procedures used in the implementation of FMEA in the company. Procedures and implementation activities of the method in the company were based on the continuous improvement cycle, as shown in the Figure 4.

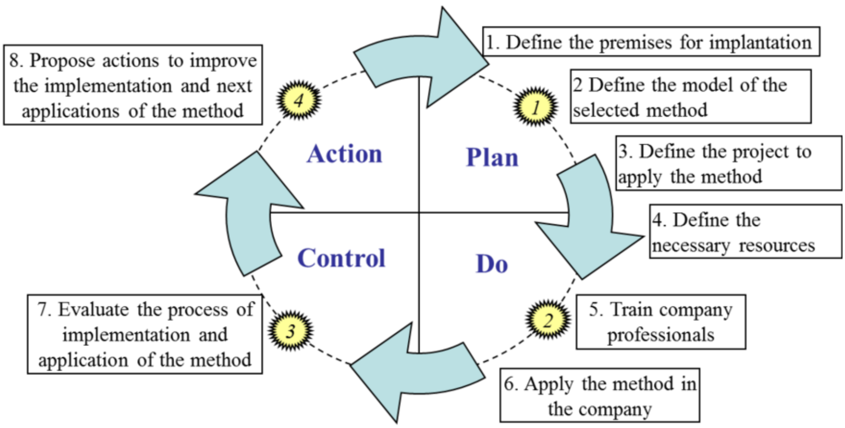


Figure 4. Stages of implementation process of FMEA method.

3.1. Define the premises for FMEA implantation

The premises in the FMEA implementation are observations, care, critical points, success factors and / or recommendations that should be highlighted when the use or implantation of the method in a company.

For sources [16], [17] and [18], the key success factor for efficient implantation and effective implementation of FMEA in the industry is the knowledge of its main concepts (failure mode, effect and cause) as described in item 3. The need to meet some prerequisites before the implementation of FMEA, among them are [18]:

- Who will be responsible for FMEA?
- Who should participate and how to participate?
- One should evaluate the system, subsystem or individual components (top-down) or must start with the components (bottom-up)?
- FMEA do It should be in an existing project for which are not considered changes?
- When to start the FMEA?
- This is the failure mode, the effect or the cause?

4. Discussion results of the implementation Process of FMEA method

4.1. Define the model of the selected method and its activities

The FMEA matrix model was defined according to the improvements needed in the ARC PDP and through a consensus of the interests of those involved in the implementation, which was reached a consensus model matrix to be used in the company, as shown in Figure 5.

The field 1 in Figure 5 corresponds to the identification of the FMEA to be performed where it is mentioned the type of application (design FMEA, process or review) and the project name to be analyzed. This first field also aims to identify the participants, implementation or revision date and the number of FMEA.

Company brand — **FMEA – Failure Mode and Effects Analysis**

Aplicação: 1 **Team:** ____________

☐ Project ☐ Process ____________ **Start date** __/__/___

☐ Project review ☐ Process review ____________ **Next review** __/__/___

Project/process name ____________ ____________ **FMEA nº** ________

Cód.	component	Function	Failure mode	Effects	Severity	Cause	Probability	Current control	Detection	RPN	Action	Responsable	Action Results			
													Sev	Prob	Det	RPN
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Figure 5. Consensus model of FMEA matrix used in the company.

4.2. Define the project to apply the method

The product design in which the FMEA was applied during the implementation process was a new product and involved all activities and stages of the EPA PDP.

4.3. Define the necessary resources

The resources required for implantation of FMEA in the company were divided into human and material resources. Human resources were the implantation coordinator, under the researcher's responsibility, and the project team, formed by the project coordinator, designers and other professionals of the company's departments participating in the activity. The financial and material resources were the computer system used Microsoft Excel software to run, formalizing and disseminating the results of the FMEA activities and teaching materials, training of professionals in the implementation of activities of the method.

4.4. Train company professionals

The training of professionals involved departments of the company were: product development, quality and processes (manufacturing). The training contained the following knowledge:

- Concepts and objectives of FMEA;

- Importance and measurable and quality of FMEA benefits;
- Main applications of FMEA (types and areas);
- Fundamental concepts in the implementation of FMEA: was to conceptualize and illustrate the failure mode, effect, cause and indexes that make up the degree of risk priority (occurrence, detection and severity);
- General on the FMEA: consisted in quoting general aspects regarding when to start an FMEA; planning, key information and basic rules (care and recommendations) for application of the method;
- General procedures in the implementation of FMEA: was to explain, in detail, all the steps for the implementation and completion of the FMEA matrix;
- Example of application of FMEA: was the demonstration of some examples of the application of FMEA (steps and main results). Such examples were obtained in sources [16], [17] and [18].

4.5. Apply the method in a project of the company

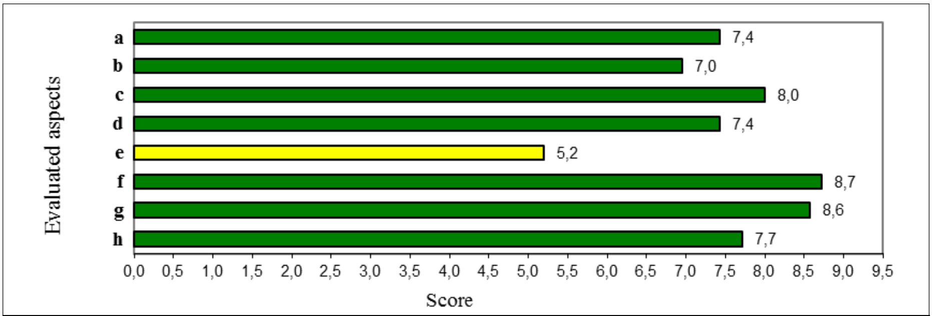
The application of FMEA in the company aimed to facilitate the implementation to demonstrate in practice the importance of the method for the PDP of the company. This practical application of the method used concepts obtained [16], [17] and [18] and consisted of the design of the following filling activities of the FMEA array of fields:

- Definition of the team responsible for implementing of the FMEA;
- Preliminary study of the product;
- Definition of the system and components;
- Identification of the functions of the components;
- Identification of failure modes of the components;
- Identification of the effects of failure modes;
- Analysis of the causes of failure modes;
- Identification of the current control of the failure modes;
- Evaluation of detection rates, occurrence and severity;
- Calculation of Risk Priority Number (RPN);
- Interpretation of FMEA;
- Development of the Action Plan.

4.6. Evaluate the process of implementation and application of the method

The FMEA implementation control consists of two evaluations, one of the implementation process and the other the validation of the importance of applying FMEA in the PDP company. The main results of the two evaluations are described below.

The evaluation of the FMEA implementation process was the critical analysis of the process of training and implementation. Such an assessment was through the questionnaire of eight implementation aspects and was answered by professionals who participated of these process, as shown in Figure 6.



ID	Evaluated aspects
a	Concepts and definitions used in the training and implementation of FMEA (premises for the implementation of FMEA).
b	General procedures adopted in the implementation of FMEA (FMEA template definition matrix and main activities).
c	Objectives set in the training and implementation of FMEA (definition of resources, project and activities to be performed).
d	Meeting the objectives set in the training and implementation of FMEA.
e	Time used in training and application of the FMEA.
f	Importance of the FMEA implementation in the PDP company.
g	Development of critical sense of the professional of the company.
h	Overall Evaluation of the training and implementation of FMEA in the company.

Figure 6. Results of the evaluation of the implementation of FMEA in the company.

It can be seen in Figure 6 that the training and implementation of FMEA met the expectations of business professionals. Note, also, that the implementation of FMEA concepts in the PDP was important for the company because it helped in the development of critical thinking in product design of the company's professionals.

The validation of the importance of applying FMEA in the company proceeded with the analysis of product failure rate. For this analysis, information was collected by the Customer Service Department, related to product failures in the field where FMEA was applied and the failures of a similar product, but without the application of FMEA, as shown in Figure 7.

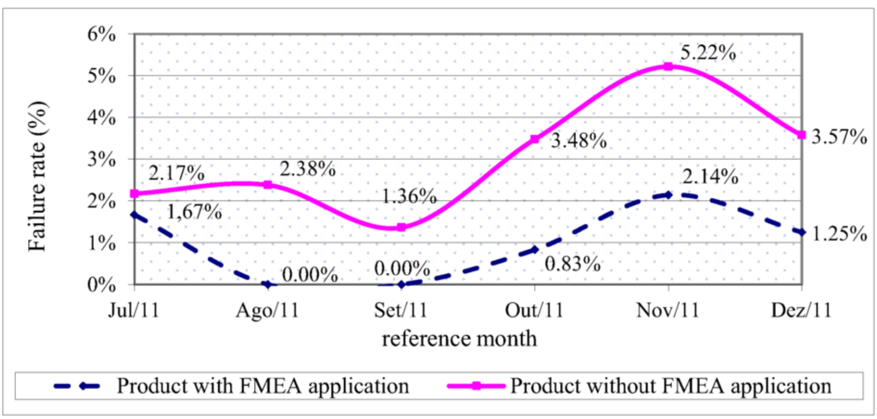


Figure 7. Impact on the failure rate of the company's products with and without FMEA application.

The failure rate (%) in each product and the period was calculated by the following formula:

$$Failure\ rate\ (\%) = \frac{Number\ of\ products\ failured}{Number\ of\ products\ sold} \qquad (1)$$

It can be seen on Figure 7 that the product failure rate when the FMEA method was applied was lower (mean = 0.98%) than the failure rate of a similar product without the use of that method (mean = 3.03%). After the evaluation, the project team realized the fundamental importance of implementing FMEA in the company's product projects, validating the method selection and implementation process.

4.7. Propose actions to improve the implementation and next applications

This step proposed improvement actions to the procedures used for the implementation and application of FMEA in the company to enable the continuous application of the method in the company. Them are:

- Preparation of a standard procedure for application of FMEA in the company, based on the procedures used in the implantation process and the experiences from in this process;
- The formation of a group in the company to discuss the main concepts related to the method in order to optimize the application;
- Additional and continuous training for the professional, to improve the understanding of the method;
- Evaluate the team's level of knowledge during training or applications of the method, aiming to provide a balance of knowledge between professionals;
- Acquire a computer system that makes possible the implementation of FMEA by Web system in order to increase the participation of the team in the project and reduce the execution time.

The FMEA process of implementation of the EPA was finalized, from the point of view of research, through the disclosure of the results to the stakeholders in the process.

5. Conclusions

After the implementation of FMEA method in the action research company, some aspects are essential for the implementation of a project method, among which are: the definition of premises for implementation of the method; the adaptation of the method and its main activities for implementation; the project definition that the method will be applied initially; the definition of the necessary resources and the evaluation of the information obtained in the method aplication.

The implementation of the FMEA methods in the company improves the product development, enabling a reduction in the failure rate of approximately 67% (3.03% to 0,98%).

It was concluded that the implementation coordinator has a key role during the process, to support the team about the knowledge of the method and speed up the execution during deployment.

Furthermore, the practical application of the method during deployment helped to demonstrate their importance for the company PDP. It is suggested that the FMEA implantation process should be used in other companies in order to validate it and increase with new and updated proposals.

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Characterizing the Value Creation in Organizations That Implement Big Data Environments

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Abstract. The identification of value creation in organizations is a complex process that involves internal and external factors to them. When applied to Big Data environments, this process becomes even more challenging because it takes also into account, from predictive analytics, the uncertainty about future processes of value creation. Big Data environments operate in a scale of large volumes of parallel-processed data; and aim to generate relevant information that otherwise would be impossible for traditional systems, especially if we expect a good performance of transaction speed and of coping with the extensive variety of data types, inherent to such environments. This paper aims to characterize the creation of value in organizations that implement Big Data. In order to fulfill this purpose, we undertook a theoretical study, which relied in a qualitative method approach of bibliographical, exploratory and descriptive nature. Finally, since this work is still on progress and it is not yet a conclusive proposal, we aim to compare our preliminary results to the typical perception of value creation, found in the literature. We also propose a discussion about the characterization of value creation in Big Data environments, to be taken further.

Keywords. Identification of value creation in organizations; Perception of value creation in organizations; Big Data; Predictive analytics.

Introduction

The term 'value' is used in different areas and application scenarios, with its sense depending on the context taken into consideration. Traditional views of value are based on the fair return created by companies and distributed to the market and consumers, usually by means of an exchange for goods or money [1].

Value creation is a complex process, especially when it involves internal and external factors to organizations. When this process is applied to Big Data scenarios, in which the use of data mining techniques – like predictive analytics – is widespread, the creation of value should be realized and recognized in a larger scale of complexity.

Organizations focusing on incremental value tends to broad their focus to include the benefits from continuous improvement. In Big Data environments, this attitude implies a willingness to adapt and actively develop a capacity to innovate. Consequently, organizations need to understand how their businesses work, and be able to measure, search, analyze and produce increasingly better outputs [2].

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Source [3] believes that the availability of large volumes of data – which is a characteristic of Big Data environments –, amplifies the difference between the actual and the possible creation of value for most organizations. New strategies and initiatives could reduce this gap, by stimulating new ways of perception of how to create value within Big Data scenarios.

In this paper, we present a survey on how the idea of value creation is understood and managed by Big Data-based companies. Moreover, we perform a comparison between this scenario and the traditional view of value creation, found in the literature. Two research questions were used as a basis for this work: (1) What is the relation between value creation and Big Data predictive analytics? (2) What is the typical view of value creation and how is it different from a Big Data perspective?

During this research, we could not found any works that specifically addressed these two questions. However, we believe that the comparison presented here could foster further discussions on how value is created and perceived in Big Data scenarios, which could be useful for both academic and business projects.

The main contribution of this paper is to propose a comparative discussion about two viewpoints: the characterization of value creation in Big Data environments and the traditional view of value creation. This approach could be useful as a support method to help designers conceive different types of information frameworks, which in turn could be more suitable to specific environments, since they would take int account all the different actors that contributed to this scenario.

The remainder of this work is structured as follows. Section 1 presents the typical view of value creation. Section 2 depicts the value concept in Big Data environments. Section 3 addresses the related works. Section 4 presents the comparison between the traditional and Big Data view of value creation. Finally, the section 5 presents the conclusions and future works.

1. Typical View of Value Creation

The nature of the term 'value' has been discussed in literature since Aristotle, over 2,000 years ago [4]. Since then, the traditional perception of the process of value creation has been formed. From the age of industrial revolution on, we can say that consumers were rarely taken into consideration as a part of this process, since it happened almost exclusively within the companies, through their activities [5] and by creating new products and services in an inside-outside flow.

According to [4], the term value was initially referred to as 'Engineering Value' and was applied to identify a function of a product or service, i.e., to establish the importance of a certain function at achieving the lowest total cost of a product/service. Over time, the term Engineering Value has been considered synonymous with 'Analysis Value', covering the following sectors: technical, productive, administrative, and financial. Finally, it is now called 'Management Value', when it ceased to be regarded as a product itself to comprehend companies' processes, such as investments, procedures, and organizational systems.

However, one remarkable difference among traditional views of value is the difficulty of making things tangible, either allowing their measurement or making them palpable. Besides, there is and the fact that these views are applied in many different areas. According to [6], in traditional contexts of accounting, the value is defined as the selling price less the cost of raw materials and production activities. In colloquial contexts, it is used to noticeable benefits for customers, and these can be tangible or intangible and are, by definition, often difficult to measure.

The terms 'value' and 'value creation' are described as essential for understanding the concept of service, defined as the application of skills and knowledge, by an entity for the benefit of another [7].

Traditional models of value creation are based on: (i) company service and price policies, where a service represents the application of skills to benefit others; (ii) system of services, represented by a set of resources, including people, information and technology, connected to other value-proposition systems; and (iii) service science, which is the study of service systems and co-creation of value within complex sets of resources [1].

In addition, it is worth mentioning that to create new or improved products/services, companies need to reallocate resources to match new features or to combine existing resources in new ways. Similar arguments appear in the literature on organizational innovation [8]. However, the characteristics of virtual markets combined with the very low cost of information processing enable profound changes in the way businesses operate and how the economic exchanges are structured. These features enable new opportunities for value creation [9].

2. Value Concept in Big Data

Big Data refers to scenarios that cannot be successfully processed by traditional technologies. These nontraditional scenarios are characterized by large volumes of data, large speed of processing and responding, and large variety of types and sources of data. Therefore, volume, velocity and variety are frequently cited by most authors as the three "Vs" that define Big Data. There is no consensus regarding the definition of Big Data, however, some authors also include value and veracity in this group of essential features of this paradigm [10].

The value in Big Data derives from insights that occur when analyzing data, for example, when analysis outcomes provide intelligence to enhance the decision-making process. In addition, there is significant value in situations where complexity is inoperable for humans [11], such as in identifying fraud in hundreds of thousands of banking transactions, as a metaphor for "finding a needle in a haystack".

The creation of value in Big Data-based organizations has been usually cited in three situations, namely [12]: (i) the reduction of uncertainty in the decision-making process, where data are used as information sources for explanatory and predictive models; (ii) the generation of improvements in products and services based on insights taken from analyzed data; and (iii) the reduction of costs, where data are used to identify fraud or the least costly investments.

For instance, the banking sector has interest in clustering customers, in order to focus its marketing efforts on the right clients, which interfere in the decision making process and cost reduction. Another important application is the detection of suspicious transactions, also referred to as fraud identification. In the health sector, we can notice the use of technologies applied to Big Data environments aiming to combine efficiency and cost reductions [13].

Big Data technologies and data management techniques have brought about an increasing interest from organizations. Several technologies and techniques used in the past as a basis for other paradigms, e.g. business intelligence, have been redirected to

Big Data scenarios, such as data science, data mining, database techniques, data management, security and privacy, data protection and integrity, data warehousing, machine learning, and predictive analytics. These data management methods in general profit from: (i) different optimization techniques that improve data analysis capability; (ii) data compression methods, which allow the creation of value from the data; and (iii) approaches that seek to extract useful information from databases [10].

Furthermore, the predictive analytics technique has been used as a tool for creating value in Big Data environments [14]. By using both Big Data and predictive analytics, we could combine business knowledge and data mining techniques for achieving business data insights. Social media, for example, offer a large volume of organizational customer data [15].

In general, the Big Data idea of value refers to the ways in which organizations get competitive benefits from data analysis. In order to summarize it, in this paper we chose to work with the concept of [12], which analyzes the creation of value in Big Data environments through three dimensions: reduction costs, insights for improvements of new products/services, and improvements in the decision-making process.

3. Related Works

In order to characterize the creation of value in Big Data-based organizations, we performed a systematic literature review in which 308 papers were found. After all the rounds of this systematic review we got 17 papers left to compose the initial basis for the research, being complemented by additional specific searches.

The identification of value creation in the collected papers is related to the research topic and the authors maintain it as a way in which value creation existence is considered in Big Data environments. We can observe different approaches to the researched issues and to the characteristics of these new technologies that we can consider as distinguished.

The work of [16], for example, say that destination management organizations could revolutionize their offerings to co-create products and dynamic services to their customers, being that the way value is created in their context. Marketing-based actions would seek to dynamically engage users in co-creation through their experiences and based on the optimization of internal and external conditions. Therefore, they used analyzes based on Big Data concepts, with a variety of data sources, such as sensors.

The work of [17] proposes a methodology to create an online digital content that corresponds to the digital visibility of companies. For the authors, the success of a brand in online platforms depends on its prevalence in the company's advertisements, online testimonials, endorsements, banners, and so on.

Industrial Cyber-Physical Systems (ICPS) projects are presented by [18]. They intend to intelligently exercise control and monitoring. The authors report that these processes are capable of performing real-time information extraction, data analysis and decision making by means of data transmission. In this case, the ICPS would play an important role in manufacturing, sales, and logistics. With the support of cloud computing technology, the ICPS development would influence the value creation of business models, services, and organization of work. Finally, these enabling technologies could also help companies achieve high quality, high yield, and low cost.

In order to explore the collection of large amounts of data in Big Data scenarios and improve supply chain innovation capabilities, [19] proposes an analytical infrastructure based on graphical deduction techniques. The authors present a case study that was conducted to evaluate the applicability of the proposed approach in the SPEC Company, a glasses manufacturer based in China. This proposed infrastructure would be able to produce potential value from different company's data sources. The results of the case study indicate that the proposed approach has allowed the SPEC Company to get new ideas for product development, understand how different sub-companies or departments can work together to optimize manufacturing processes, and produce new fashion products more profitably. The business analysis intends to create value from data. Based on this statement, [20] presents a structural framework to derive value from business analysis, which indicates how to extract value from data and argues that the creation of value requires: (i) alignment strategy and behaviors desirable for companies; (ii) performance management together with tasks; and (iii) analytical capabilities.

By addressing the value of Big Data-based services, [21] intends to inform the managers of manufacturing companies about the fifth "V" feature, represented as an additional layer of aggregated value, hidden in a service. According to the authors, the data generated by services could become the basis for competitive advantage, since they could provide valuable information on a particular market that competitors could have or not extracted insights for new products.

Another approach [22], which intends to develop and validate a predictive model of hospitalization costs after spine surgery, developed a study to address the various initiatives put in place to minimize health costs. The predicted and observed values show good correlations. Various socioeconomic variables, as well as patient and hospital levels were factors associated with increased costs after spine surgery. Based on these data, a predictive cost model after spine surgery was developed and validated.

By emphasizing data mining methods, [23] seeks to access key data hidden in unstructured text news. The paper addresses a specific context, bringing together natural language processing, statistical pattern recognition, and sentiment analysis to propose a system that provides insights for movement of the currency market based on the words placed in newspaper headlines. In a consumption analysis study, [24] merged Big Data concepts to analyze consumer behavior. Following the authors, the data provide behavioral information about consumers that enable the translation of these data into market advantage insights. This analysis refers to tools that help find hidden data patterns.

Source [25] proposes Big Data solutions for the organization management process and to support decision making and optimize business processes. The work shows some ways to create value by using technologies applied to Big Data scenarios. It focuses on the creation of transparency, by making large volumes of data more accessible to stakeholders in a timely manner, allowing experimentation to discover the needs, exposing the variability and improving performance, collecting more accurate and detailed performance data, targeting populations and customizing actions, replacing and supporting human decision with automated algorithms, and finally, innovating in business models, products and services.

Seeking to explore aspects of definition, distinguishing features, types, business value and challenges for Big Data analysis (BDA) in e-commerce scenarios, [26] discusses about the opportunity for e-commerce companies in extracting business value from BDA perceptions, in order to solve business problems and aid the decision-making process. The work of [27] talks about the best practices to deploy an enterprise application, in order to ensure a data stream with consistent semantics related to the Linked Open Data (LOD) paradigm. They argue that the implementation of LOD tools and procedures does not always require the project to start from scratch; it could be deployed on top of existing applications, which would ensure low cost implementation and integration. For the authors, the benefit of the adoption of linked data technologies in business is multidimensional. It could solve the problem of heterogeneous data and integration within the company by creating value chains within and between enterprises, creating meaning in data, allowing the search of relevant information, and increasing the value of new data and insights for competitive advantages.

According to [28], more companies are adopting the concept of time-strategic decisions for supply purchases with the intention to create value and achieve competitive advantage. The supply process usually involved people buying what they were told by their superiors to buy. From a management viewpoint, there was little belief that the supply could add value to the company. However, data supply have become an important source of information for decision-making and played an increasingly important role for the company, mainly by reducing costs and ensuring the availability of the inputs.

Source [29] briefly explores five potential design points on combining Big Data with supply chain, by using: (i) Big Data and predictive analytics; (ii) manufacturing additives; (iii) autonomous vehicles; (iv) science of materials; and (v) supply chains without borders. They say that predictive analytics provide great insight correlation, i.e. it could help decision makers. Moreover, companies would be monitoring customer behavior like never before, by using these analyzes to build profiles that could be used to develop new products, manage product portfolios, redesign exhibition of products, develop targeted promotions, and optimize prices.

In health domain, in order to control the spread of diseases into new areas, [30] presents a study on a mapping system, which would support this objective. The research focuses on data points that would have the greatest potential impact on the risk map, because these data are outside of the current range and / or currently planned areas to be inadequate. According to the authors, many groups have used the captured data from the Internet, including social media, to analyze temporal trends in diseases such as influenza, characterized by large peaks of incidence to detect faster outbreaks than traditional methods. In this sense, these methods could be used to minimize uncertainty in the decision making process.

In healthcare, to better understand the ways clinicians interact with data and visualization technology, such as the diagnosis of patients and workflows, [31] conducted a survey to assess how health data visualization can increase situational awareness, maximize the usefulness of patient data and improve the process of clinical decision-making in critical care environments. According to them, the literature indicates that there are a number of heuristic approaches to consider. The benefits of a simultaneous processing of information through visualization techniques can be measured by decider confidence metrics and perceived decision-making facility.

The work of [32] aims to support decision-making by discovering patterns and other useful information from large data sets. The goal is to appropriately find a travel plan, according to the customer's specific requirements, without checking all combinations of all services and tasks. According to the authors, data analysis in Big Data scenarios provide support for decision making to discover patterns and other useful information from large data sets.

4. Discussion

In this section, we present a discussion between the traditional and Big Data viewpoints on value creation. To characterize value in Big Data contexts, we selected 17 papers related to this topic in order to identify their ways of characterizing the creation of value, based on the three concepts of [12]: reduction of uncertainty in the decision-making process, generation of improvements in products and services, and cost reduction.

Table 1 - Characterization of Value Creation in Big Data Scenarios

Type	Quantity	Works
Decision Making	13	Acito and Khatri (2014) Akter and Wamba (2016) Barnes et al. (2015 Chang et al. (2015) Erevelles, Fukawa and Swayne (2015) Fawcett and Waller (2014) Ketchen Junior, Crook and Craighead (2014) Koswatte et al. (2015) Moyes et al. (2015) Ngo et al. (2015) Seker and Eryarsoy (2015) Zhou et al. (2015) Ziora (2015)
Insights of Products and Services	10	Acito and Khatri (2014) Akter and Wamba (2016) Buhalis and Foerste (2015) Chang et al. (2015) Erevelles, Fukawa and Swayne (2015) Fawcett and Waller (2014) Mezaour, van Nuffelen and Blaschke (2014) Opresnik and Taisch (2015) Zhou et al. (2015) Ziora (2015)
Reduction of Costs	4	Acito and Khatri (2014) Ketchen Junior, Crook and Craighead (2014) Missios and Bekelis (2015) Zhou et al. (2015)

In a first analysis, it was found that 13 out of 17 selected items were related to value creation as part of the improvement in decision-making processes, which represents 76.47% of the papers [17, 18, 19, 20, 23, 24, 25, 26, 28, 29, 30, 31, 32]. The generation of insights for new products and services was cited as value creation in 10 papers, representing 58.82% of the total being [16, 18, 19, 20, 21, 24, 25, 26, 27, 29]. Regarding the cost reduction, it was found that 4 papers were related to value creation [18, 20, 22, 28], which represent 23.54% of the total.

It was observed that only two papers referred to the creation of value with the three simultaneous characteristics [18, 20]. Four other works cited value creation for improved decision-making and generating insights for improvement or generation of new products and services [19, 24, 25, 26]. Only [28] concurrently cited the creation of value characterized as improvement for decision-making and reduction of costs.

Six articles cited improvement in decision-making as the characterization of value creation [17, 23, 29, 30, 31, 32]. Another 3 papers mentioned that the creation of value was cited as insights for improvement and products and services [16, 21, 27]. Finally, only one paper [22] cited cost reduction as the only way to create value in their work. Table 1 summarizes this analysis.

Therefore, we can observe that there are similarities and differences when comparing traditional views of value creation to Big Data ones. The main similarities between them are the search for cost reduction and for improvements in products/services. However, even with the same objectives, traditional or Big Data approach to value creation differentiate from each other according to the environment. In Big Data scenarios, massive data analytics plays a major role in generating new insights for product/service improvement. In traditional scenarios, such improvements originate from organizational activities in company's processes and daily activities or, as depicted in [4], we could use market research personnel to define the customer requirements, including price.

In addition, we can observe that the majority of Big Data-based works consider that the creation of value is related to improving the decision-making processes. Differently, the traditional literature has increased its focus on identifying more economic alternatives to perform functions related to product/service development.

It should be noticed that the decision-making process in many cases is present in situations where it is identified as insight for improvements or proposals of new products/services or cost reduction, which makes it even more present in Big Data value creation scenarios. In turn, traditional views of value creation focus mainly on cost reduction and product/service development.

In cases of co-creation of value, where users interact with business and take part into the improvement or creation of new products, there are some operational differences in the interactions. This occurs because in Big Data environments these contributions can also be collected through data mining process on customer historical data, reflecting habits and preferences, as well as in the case of travel itineraries.

Since Big Data operates in a very large scale of volume of data, its analytical processing is not limited to statistical percentages, but about the whole set of data available for analysis. That is, 100% (or almost) of the dataset can be analyzed, which produces higher degrees of accuracy.

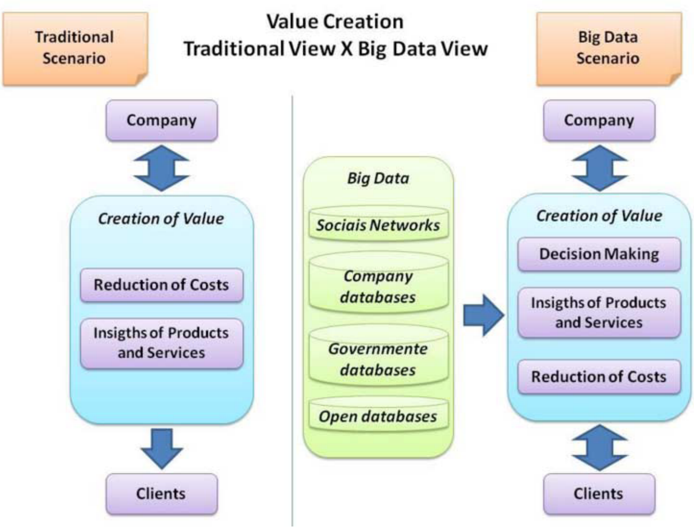

Figure 1. Traditional View *versus* Big Data View of Value Creation.

This ability to process very large and varied amounts of data in high speeds, unreachable by traditional paradigms, is a differential related to Big Data scenarios. In this paradigm, advanced analysis and new sources of information can be explored, since they may represent new ways to support decision-making in organizational environments.

Figure 1 shows a comparison between traditional and Big Data views of value creation. In traditional view, the company supplies information to create value, with its focus on improving products and services, cost reduction, where the customer is the final part of the process. In Big Data view, in contrast, the company and customers create historical data, which are stored on social networking databases, business, and governmental and open databases, among others. This Big Data dataset feeds information to the value creation process, which returns benefits for the customer and for the company.

5. Conclusions and Future Work

In this study, we aimed to characterize the creation of value in organizations that implement Big Data, comparing it to the traditional view of value creation, found in the literature. In this sense, we have found some similarities and differences.

The similarities stand for cost reduction and improvements in products and services while using very large and varied datasets, analyzed in high speed of processing. The main difference is that Big Data strategies focus also on improving the decision-making process, unlikely the traditional approaches.

Since this is a work still in progress, we consider as limitations of it the non-exhaustive list of documents analyzed here, mostly of academic nature. As future work, we intend to develop application tools for measuring the generation of value creation, which will be applied to some case studies. The goal will be to stablish a comparison between actual outcomes and the works found in the literature.

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Offshore Wind Turbine Life-Cycle-Cost Evaluation in Taiwan Under Impacts of Maintenance and Harsh Weather Conditions

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Abstract. Advances in technology have promoted offshore wind energy being one of the most promising renewable energy sources. Offshore wind farms are usually positioned in an opened space far away from the seashore where the wind is strong enough to generate electricity effectively and reliably. However, due to location characteristic hard–to–reach, the operation and maintenance cost of the offshore wind farms are high and the economic evaluation is uncertain. A huge number of researches about offshore wind energy have emerged recently in response to these issues. However, the researches considering the effects of various influential parameters to access the reliability of offshore wind turbine remain small and still limited, especially the parameters related to the dynamic weather conditions such as real-time utilization under typhoon and flood impacts. This paper proposes an approach to analyze the life–cycle–cost of the offshore wind turbines under maintenance scenarios and environmental influences, with the support of probabilities distribution method. The electricity generated by the offshore wind turbine is calculated based on the real weather conditions collected in a variety of locations throughout Taiwan such that the proposed life–cycle–cost model is more reliable and accurate than the conventional approaches. The results show that Typhoon and Maintenance cost occur 4.2% and 19.6% respectively. Moreover, offshore wind energy is an excellent environmental solution with high economic benefit on sites where the wind resource is abundant.

Keywords. Offshore wind energy, Life–cycle–cost, Cost estimation, Economic analysis, Maintenance, Harsh weather condition

Introduction

As an inexhaustible and free energy source, offshore wind energy has become a potential alternative for many countries to overcome the negative impacts on the environment of fossil fuels. Energy generated from offshore wind is rapidly emerging as one of the most important clean and renewable sources in the world. Despite the

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enormous wind sources, the installation capacity of offshore wind energy still remains a small portion. One of the key factors for this limitation is offshore wind system usually positioned far off coastline, causing high investment and risks, technological and logistical challenges. Moreover, while the technical feasibility of wind energy system may be visible in the technical documents and in most studies of wind energy [1-5], its economic evaluation under the real weather condition, maintenance, is limited.

Due to lack of indigenous conventional energy resources, development of wind energy has become an important issue for Taiwan's future energy supply. Based on outstanding benefits of the potential wind capacity and Taiwan's geographical location, offshore wind energy is regarded as one of the most attractive renewable energy to be developed. Recently, a huge number of studies of wind energy have been proposed. For instance, a list of 70 life cycle assessment research publications on wind energy was reviewed by [6]. Nevertheless, only 3% of them consider the "Business management: planning, financial, and administrative requirement", in which it is a few number of studies considering impacts of various influential parameters such as the practical weather conditions (typhoon and flood), and providing accurate and reliable economic evaluation based on those practical data. Therefore, the need for a accurate economic evaluation of the offshore wind system under consideration to the impacts of the real weather condition (including harsh weather condition such as typhoon and flood), the maintenance period and maintenance cost, is required.

In this paper, an approach to access the life–cycle–cost of the offshore wind turbine under the impacts of various influential parameters is proposed. The influential parameters are impacted by the maintenance cost during maintenance period (including labor cost, cost of power lost, transportation and replaced equipment cost), the real weather conditions (including harsh condition such as typhoon and flood). The variety of locations over Taiwan is taken into account to calculate the generated electricity according to the local weather condition in each location. In order to estimate the failure rate of each component of the offshore wind turbine system for maintenance, Weibull probability distribution is used in this paper.

1. Methodology

1.1. Offshore wind system life–cycle–cost overview

The framework addresses a life cycle cost (L_C) estimation process is shown in Fig. 1. As shown in Fig. 1, the L_C is the total cost of a wind turbine system during its lifetime including the capital cost; maintenance cost (preventive maintenance cost and corrective maintenance cost) and assembles cost against the harsh weather conditions. According to [7], the portion of the maintenance cost is 18% to 30% of the total L_C and the corrective maintenance cost is 30% to 60% of the total maintenance cost [8]. Besides the direct costs (to fix the failed components), the costs of production loss (generated electricity) due to inactiveness of the wind turbine also contribute considerably to the maintenance cost. Wind turbine is a combination of a number of critical components, and the electricity is generated only if all of these critical components are functional. Therefore, when a failure occurs for any critical component of the wind turbine, the entire wind turbine system has to be stopped for a certain period of time until the failed critical component is totally repaired. This period causes a loss of production (generated electricity) that must be considered in the life–cycle–cost analysis through the cost of production losses. Consequently, the L_C analysis method in this paper considers the real utilization time of the offshore wind system and the real electricity generated due to the harsh weather conditions and maintenance occasion.

In order to match the proposed approach to Taiwan, the weather conditions on a variety of locations throughout Taiwan, including majority of cities and counties are collected to calculate the real electricity generated in Taiwan.

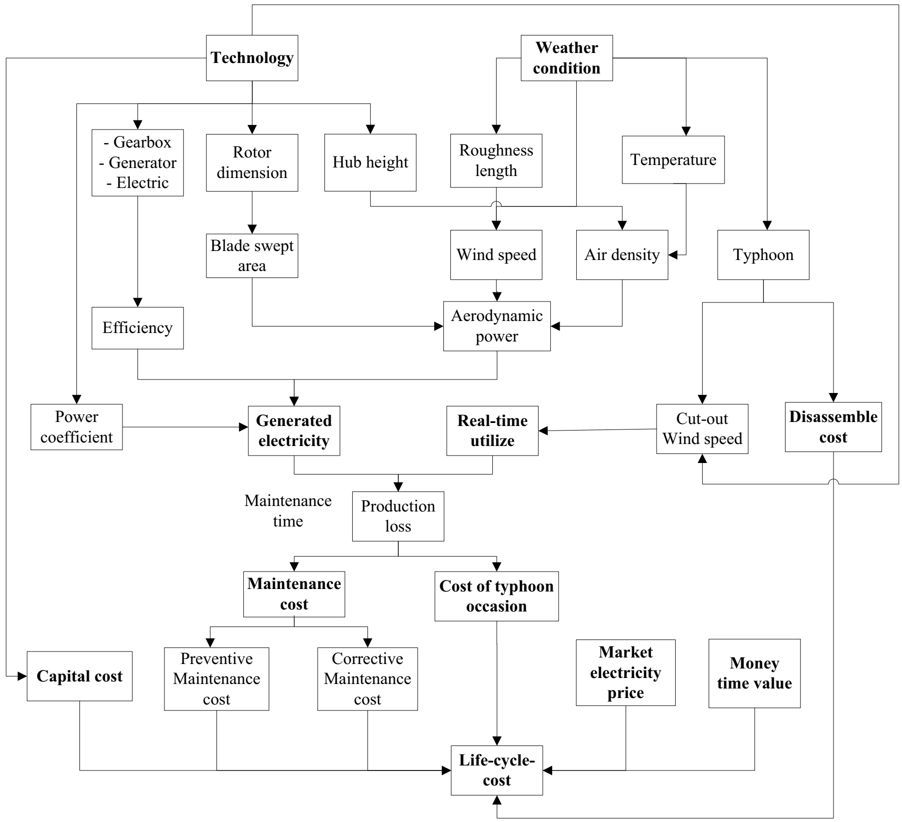

Figure 1. Life–cycle–cost estimation framework

1.2. Offshore wind system life–cycle–cost overview

1.2.1. Generated Electricity

As aforementioned, the production loss when a failure occurs for any critical component of the offshore wind turbine must be considered in the life–cycle–cost analysis through the cost of production losses. Moreover, to access the offshore wind system in a reliable and accurate manner, the economic analysis requires the generated electricity which is actually influenced by the environmental and weather conditions. The real generated electricity is typically significantly different from the theoretical generated electricity due to the impacts of environmental factors [9]. The method for computing the generated electricity in this paper carefully considers technical parameters and the influences of environmental conditions in variety of locations throughout Taiwan (12 cities and counties), so that the generated electricity estimates are more accurate and feasible for Taiwan. The nomenclature used hereafter is clearly illustrated in table 1.

The effective generated electricity (P_{op}) from a wind turbine to feed into grid is a function of the aerodynamic power (P_{pw}), under the efficiency of the gearbox (η_1), generator (η_2), electric (η_3) and the turbine power coefficient (C_P), is derived by equation (1).

$$P_{op} = C_p \eta_1 \eta_2 \eta_3 P_{pw} \tag{1}$$

in which the aerodynamic power (P_{pw}) of an air mass that flows at speed (v) through an area (A) of wind turbine generator can be calculated as follows:

$$P_{pw} = \frac{1}{2} v_h{}^3 A\rho = \frac{1}{2} v_h{}^3 \pi R(R+2r) \frac{\varphi}{GT}^{\frac{-gh}{GT}} \tag{2}$$

The blade swept area $A \approx \pi R^2$ when R >> 2r due to doubling the length of wind blades, the swept area can be increased by the factor up to 4.

Due to the increase in wind speed with altitude, evaluating for the effects of wind speed requires knowing the wind turbine hub height (h), and an approximation of surface roughness conditions (z_0). The surface roughness (z_0) of the sea is low compared to land surfaces. This is the main reason for the high wind speed of offshore wind turbines [10].

Therefore, the effective generated electricity from a wind turbine to feed into a grid is given by:

$$P_{op} = \frac{1}{2} C_p \eta_1 \eta_2 \eta_3 \left(v_{ref} \times \frac{\ln \frac{h}{z_0}}{\ln \frac{h_{ref}}{z_0}} \right)^3 \pi R(R+2r) \frac{\varphi}{GT}^{\frac{-gh}{GT}} \tag{3}$$

C_p represents the power conversion efficiency of a wind turbine and C_p is a function of the tip speed ratio, as well as the blade pitch angle in a pitch controlled wind turbine [8]. According to [9, 12], the theoretical maximum power coefficient reaches its maximum value of 0.593, a value determined by a fluid mechanics constraint known as the Betz limit. Hence, even if power extraction without any losses were possible, only 59% of the wind power could be utilized by a wind turbine.

The practical generated electricity of the offshore wind system could be calculated using the equation (3), wherein the wind speed (v_{ref}) is the wind speed at 10 meters above the sea level. In this paper, the wind speed data and weather conditions are collected from 12 different locations throughout Taiwan (12 different cities and counties), and the maintenance period and the types of maintenance are decided by the Weibull probability distribution. As such, the generated electricity in this paper is considered as the practical generated electricity of the offshore wind system in Taiwan.

Table 1. Nomenclature used in this paper.

	Power generation		Economic evaluation
P_{op}	The output power (W)	L_c	The Life – cycle – cost
C_P	The turbine power coefficient (%)	C_s	The capital cost
η_1	Gearbox efficiency	C_i^{cm}	Corrective maintenance cost in year i
η_2	Generator efficiency	C_i^{pm}	Preventive maintenance cost in year i
η_3	Electric efficiency	C_i^{as}	Disassemble cost if typhoon occur in year i
P_{pw}	The aerodynamic power of wind turbine generator (*W*)	$C_i^{P_T}$	Power loss cost if typhoon occur in year i
ρ	Air density (*kg/m*^{3})	C_i^L	Labor cost if a maintenance task is done
φ	Local air pressure (101325 Pa)	C_r^k	Replaced equipment cost of component *k*
R	Length of wind blades (*m*)	C_i^{trans}	Transportation cost (*$/km*)
r	Radius of the hub (*m*)	D	Distance to wind farm from seashore *(km)*
v_h	Wind speed at the height *h* (*m/s*)	P_i^e	Market electricity price in the year i (*$/kWh*)
v_{ref}	Wind speed at reference height *(m/s)*	τ_m	Time of a maintenance occasion (*hour*)
T	Local air temperature (*K*)	τ_T	Time of a typhoon occasion (*hour*)
G	Gas constant for air (287.05 J/kg-K)	τ_{as}	Time of a assemble occasion (*hour*)
z_0	Roughness length in the current wind direction (0.0001m with water surface)	β	The discount factor ($\beta = 1/(1+r_i)$ where r_i is the interest rate)
g	Gravity constant (9.81 *m/s*^{2})	h	Altitude above sea level (*m*)

1.2.2. The impact of typhoon to offshore wind system

With geographical characteristic located in North Pacific Ocean typhoon – prone area, every year an average of 3 to 4 typhoons pass through Taiwan. According to Taiwan Center Weather Bureau' statistics, there were 405 typhoons that hit Taiwan in the period from 1897 to 2014. The typhoon damages to offshore wind turbine and reduces system reliability. For instance, on September 28th 2008, typhoon Jangmi struck Taiwan with strong wind that brought down a large-scale wind turbine tower located in the Taichung harbor area. Typhoon Soudelor has hit Taiwan with damaging wind and caused damage worth an estimated NT$560 million (US$17.67 million) to eight wind turbines operated by Taiwan Power Company in 2015 [13]. Frequent typhoon raise great risks and obstacles to the development of offshore wind system, and increase life-cycle-cost of offshore wind turbine. This paper proposes a method to evaluate life cycle cost under the risks of typhoon on offshore wind system in Taiwan.

For offshore wind turbine, the mechanical brake would stop the turbine from rotating when the wind is too strong (above the cut out speed of 25 m/s). In general, once a typhoon occurs, there will be a high risk of grid failure, since it is not possible to adjust or stop the turbine and over-speed wind can damage the mechanical and electrical components. In more severe conditions, extreme high loads would cause the collapse of the turbine or breaking blade might hit and induce its tower to collapse.

It is supposed that wind turbine can withstand typhoon when wind speed in typhoon are lower than the cut out speed of turbine (Usually 25 m/s). The damage ratios of turbine become 100% when extreme wind speeds of typhoon reach the upper bound wind speed that is turbine could stand (α) (usually 75 m/s). When this situation occurs, disassembling the system is required to reduce the damage induced by typhoon. If wind speed is in interval between the turbine's cut out wind speed and the upper bound wind speeds (α), mechanical brake would stop the turbine from rotating without the need for disassembling the wind turbine. Therefore there is no cost for disassembling the wind turbine, however in this period the cost of production loss should be added in life cycle cost of the system.

1.3. Life–cycle–cost model formulation

a. Maintenance cost

Maintenance is desired component performance by maintaining or returning the component's ability to correctly function [14]. The maintenance cost includes corrective maintenance cost (C_i^{cm}) and preventive maintenance cost (C_i^{pm}).

Let *F(i)* denotes the probability that a component fails in the year i with the failure rate function following the Weibull distribution.

$$\text{F(i)} = \frac{\varepsilon}{\sigma}\left(\frac{i}{\sigma}\right)^{\varepsilon-1} e^{-\left(\frac{i}{\sigma}\right)^{\varepsilon}} \tag{4}$$

where ε is the scale parameter and σ is the shape parameter. When $\varepsilon = 1$ the failure rate is constant and the Weibull distribution is equal to the exponential distribution. Because the failure rate of offshore wind turbine increased with time as ageing component, the scale parameter will greater than 1 ($\varepsilon > 1$).

Let [ψ, γ] denote for lower bound and upper bound of the failure interval. Call x_i^k and y_i^k are the binary variables denoted for the corrective occasion and the preventive occasion performed at year i. And χ_i denotes for the binary variables whether maintenance occasion is performed in year i.

$$x_i^k = \begin{cases} 1 & \textit{If} \;\; F(\text{i}) > \gamma \\ 0 & \textit{Otherwise} \end{cases} \tag{5}$$

$$y_i^k = \begin{cases} 1 & \textit{If} \;\; \psi \le F(\text{i}) \le \gamma \\ 0 & \textit{Otherwise} \end{cases} \tag{6}$$

$$\chi_i = \begin{cases} 1 & \textit{If} \;\; \sum (x_i^k + y_i^k) \neq 0 \\ 0 & \textit{Otherwise} \end{cases} \tag{7}$$

Maintenance is performed if any of the preventive maintenance or corrective maintenance task is performed. The component k will received corrective maintenance at the year i if $F(i) > \gamma$. The component k will received preventive maintenance at the year i if $\psi < F(i) < \gamma$. And no maintenance occurs when $F(i) < \psi$.

Consequently, the maintenance cost in year i (C_i^m) is derived as follow:

$$C_i^m = \left(\sum_{j=1}^{k} x_i^k c_r^k + \sum_{j=1}^{k} y_i^k c_r^k \right) + \chi_i \left(C_i^L + D \times C_i^{trans} + P_{op} \tau_m P_i^e \right) \tag{8}$$

b. The costs occur in a typhoon occasion

As aforementioned, when the typhoon occurs with the wind speed greater than the upper bound wind speed (α), disassembling the wind turbine system is required to reduce the damage induced by typhoon. As a result, the cost for disassembling the wind turbine and the cost of production loss due to inactiveness of the wind turbine are added to calculate the life cycle cost. Otherwise, if the wind speed of the typhoon is in interval between the turbine's cut out wind speed and the upper bound wind speed (α), the mechanical brake would stop the turbine from rotating without the need for disassembling the wind turbine. Consequently there is no cost for disassembling the wind turbine, however in this period the cost of production loss should be added in life cycle cost of the system.

Let $\left[W_L, W_B\right]$ respectively denote the cut-in wind speed and cut-out wind speed. It is noted that the wind turbine is normally operated when the wind speed is greater than the cut-in wind speed and lower than the cut-out wind speed. A typhoon occurs when wind speed is greater than the cut-out speed (w_i): $w_i > W_B$. Call α is the upper bound wind speed which is the maximum wind speeds allowing the wind turbine withstands without damage. Thus, the cost for disassembling the wind turbine is occurred only when wind speed (w_i) is greater than the upper bound wind speed ($w_i > \alpha > W_B$). Call s_i and z_i are the binary variables denoting whether the disassembling operation and the production loss occurred in typhoon occasion at year i.

$$s_i = \begin{cases} 1 & If \;\; w_i > W_B \\ 0 & Otherwise \end{cases} \tag{9}$$

$$z_i = \begin{cases} 1 & If \;\; w_i > \alpha \\ 0 & Otherwise \end{cases} \tag{10}$$

Consequently, the costs occur in a typhoon occasion is derived as follow:

$$C_i^T = s_i P_{op} \tau_T P_i^e + z_i \left(C_i^L + D \times C_i^{trans} + P_{op} \tau_{as} P_i^e \right) \tag{11}$$

c. Life cycle cost model

The Life–cycle–cost of an offshore wind system is the total cost during its lifetime including the capital cost, maintenance cost (preventive maintenance cost and corrective maintenance cost) and disassembling cost against the harsh weather conditions, in which the annual maintenance cost during the life cycle of the wind turbine is not always the same due to the variation of time value of money. Therefore, it's necessary to discount the maintenance cost of every year to current time point with discount rate (β) such that calculated life-cycle-cost is accurate and reliable. The life–cycle–cost model formulation is derived by equations (12) and (13) below.

$$L_c = C_s + \sum_{i=1}^{n} (C_{cm}^i + C_{pm}^i + C_{P_T}^i + C_{as}^i) \beta^i \tag{12}$$

$$L_c = C_s + \sum_{i=1}^{n} \left[\begin{array}{l} \left(\sum_{j=1}^{k} x_i^k c_r^k + \sum_{j=1}^{k} y_i^k c_r^k \right) + \chi_i \left(C_i^L + D \times C_i^{trans} + P_{op} \tau_m P_i^e \right) \\ + s_i P_{op} \tau_T P_i^e + z_i \left(C_i^L + D \times C_i^{trans} + P_{op} \tau_{as} P_i^e \right) \end{array} \right] \times \beta^i \tag{13}$$

where the nomenclature used in the equations (12) and (13) are illustrated in table 1.

2. Results and discussion

The proposed approach calculates the life–cycle–cost for an offshore wind system with 50 turbines located in 12 different locations in Taiwan, each of the turbines has 4 critical components including rotor, bearing, gearbox and genarator. The daily climate data used for this study is collected from 2003-2015 and mainly collected from "Taiwan Central Weather Bureau".

In this paper, the Vesta V82 wind turbine is used for calculation. According to (15), Vesta contributes the highest percentage in the worldwide turbines manufactures with 34%. Further, V82 has been installed by many countries due to its highly efficient operation and flexible configuration. The parameters of a typical V82 are provided in table 2 by the manufacturer.

Table 2. Parameters of Vesta V82 offshore wind turbines.

Items	Parameters
Diameter	82 m
Swept Area	5281 m2
Tower height	78 m
Rated Power	1.65 KW
Cut-in wind speed	3-5 m/s
Cut-out wind speed	25 m/s
Nominal wind speed	12 m/s

Using the collected climate data and equations (1–3), the monthly averaged values of the wind speed, the temperature, the air pressure, and the power generation of offshore wind system which located in 8km distance from shore, are calculated and shown in Figure 2.

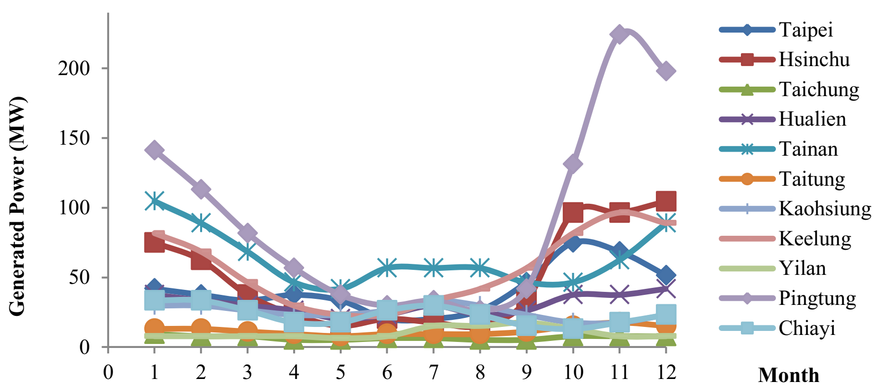

Figure 2. Generated power at each location monthly.

The results show that wind speed has the most impact to the offshore wind system. Due to the difference of wind speed at different locations, the generated power departs significantly among the investigated locations. For instance, Penghu has the highest wind speed with 8.5m/s in average and with maximum up to 11m/s. Accordingly, the average power generated is also the highest with 1254 MW. By contrast, Taichung has the lowest wind speed and the power generated is also lowest with the average of 7MW.

This paper proposes an approach to analysis real time utilization of the offshore system during life cycle time. As shown in figure 3, each year offshore wind turbine activates with 83% time, and deactivates 17%, in which 3.2% due to typhoon, 2.3% due to extreme wind speed and 10.5% due to deactivated components.

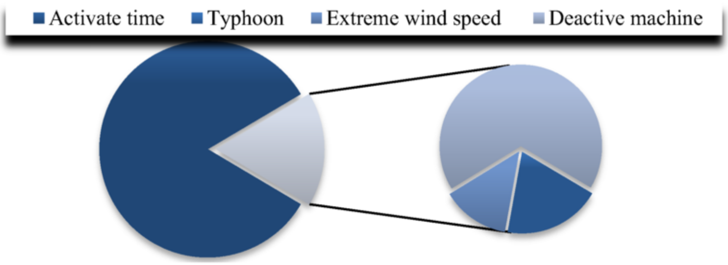

Figure 3. Real time utilization of offshore wind turbine.

According to Taiwan Center Weather Bureau, Taiwan has average of 6 typhoons annually and a severe typhoon in each three years; bring out many damages for offshore wind turbines. The results of the proposed approach show that life cycle cost of the wind turbine increases 4.5% by the damage of the typhoon (shown in Figure 4).

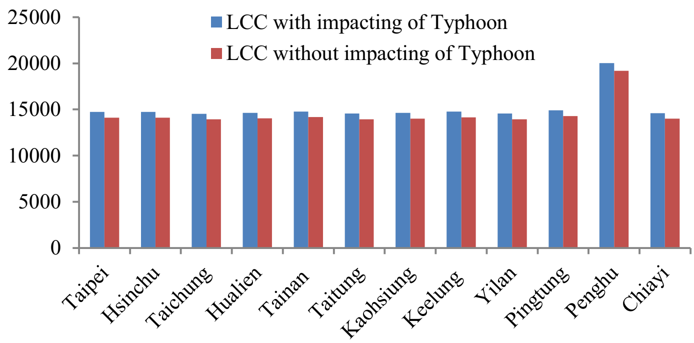

Figure 4. Offshore wind turbine life–cycle–cost with and without impacting of typhoon.

Although Penghu has the highest life cycle cost, the benefit of the offshore wind system in this place is the highest due to the highest power generation.

As shown in figure 5, in the life cycle time, an offshore wind turbine system needs to pay 19.6% for maintenance cost, 6.1% for operation cost, and 4.2% for typhoon occurred cost.

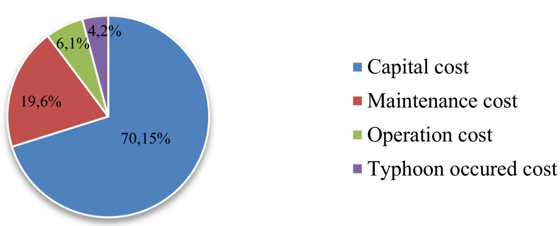

Figure 5. Life–cycle–cost components of offshore wind turbine.

3. Conclusions

While natural resources are limited and environmental problems are becoming more seriously the offshore wind energy with its advances is considered as one of the best solution for future energy needs. In order to confirm the benefit of the offshore wind system, this paper proposes a new approach to analysis life–cycle–cost of the offshore wind system under the influences of maintenance and typhoon.

Besides examining the aspect of harsh weather conditions, this paper also considers other aspects in maintenance cost such as different failure modes of the components and time of maintenance action to estimate production loss. All these factors render critical implications in the actual offshore wind system life cycle cost.

The case study of 12 locations in Taiwan shows that the life–cycle–cost is considerably lower when the impacts of typhoon are not considered. However, it is lack of accuracy and reliability when such an important weather condition as typhoon is not considered in calculating the life cycle cost of the offshore wind system. The results also show that offshore wind energy is an excellent environmental solution with high economic benefit on sites where the wind resource is abundant.

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Part 15

Multi-Disciplinary Design Optimization

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Simulation of Crash Tests for Electrically Propelled Flying Exploratory Autonomous Robot

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Abstract. The need for continuous technical development brings fresh innovatory solutions and at the same time indicates new trends. For years, common applied solutions have not been adequate enough to the newly established and evolving needs. Furthermore, the global development brings new challenges and needs for the aviation propulsions. An example of such a problem can be particularly noticeable in recent years, with the growing popularity of remotely controlled, small flying objects, commonly called drones, which designated new opportunities in the field of aviation, as well as become a source of new needs. An unusual challenge is the application of a drone in extremely difficult weather conditions or surrounding conditions causing its multiple and relatively strong bounce off the obstacles that may occur while using the drone to inspect ventilation ducts, in confined areas with a large number of installations, in dense forest conditions or in space with strong turbulent atmospheric conditions. In such cases it is not possible to avoid multiple collisions with various obstacles. It is necessary to design drone and its drive so that such collisions will not damage the flying object and moreover that maintenance of the full control of the drone will be possible. As the answer to those needs a drone was designed with a passive protection system. To protect against the collision consequences, the static parts of the drone—the power supply, controllers, motors and extension devices as well as the rotating parts—propellers are covered outwardly with a protection shield. In this paper the behaviour of the protection system of flying autonomous robot's propulsion during collision with perfectly rigid obstacle was checked. The performed numerical crash analysis simulates probable collision situations in operating conditions specific for the researched drone.

Keywords. Finite element method, Autonomous flying robot, Damage resistance, Collision simulation

Introduction

The need for continuous technical development brings fresh innovatory solutions and at the same time dictates the new trends. For years, common applied solutions are getting not adequate enough to the newly established and evolving needs. Due to the sustainable development of related science fields, many of the opposites in application of new technology in aviation are eliminated, which creates new possibility for

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designers. For years the main issue of our civilisation has been to manufacture and explore goods with fuel consumption and emission of harmful chemicals into the atmosphere at as low level as it is possible [1, 2]. The global environmental protection problem connected with economics becomes a major factor driving the need for the development and introduction of innovative aviation propulsions. On the other hand, there still exist previously unsolved problems of classical methods of implementation of aviation propulsion. Furthermore, the global development brings new challenges and needs for the aviation propulsions. An example of such a problem can be particularly noticeable in recent years, the growing popularity of remote-controlled, small flying objects, commonly called drones, the use of which designated new opportunities in the field of aviation, as well as becomes a source of new needs. An unusual challenge is the application of a drone in extremely difficult weather conditions or ambient conditions causing its multiple and relatively strong bounce off the obstacles that may occur using the drone to inspect ventilation ducts, in confined areas with a large number of installations, in dense forest conditions or in space with strong turbulent atmospheric conditions. In such cases it is not possible to avoid multiple collisions with various obstacles. It is necessary to design drone and its drive so that such collisions will not damage the flying object and besides such collisions will not prevent the full control of the drone. In the case of small drones one of the most popular propulsion systems system is quadrocopter [3]. To protect the rotating parts of drones in the cases where there is a possibility of contact with obstacles the guards in the propellers spinning plane are applied. In difficult conditions this solution is not sufficient and does not prevent propellers from collision with foreign elements. Much more reliable protection is the openwork or external mesh cover of the whole drone. Such solutions are known to protect drone with a coaxial counter-rotating propellers system. In the case of such mesh cover, design solution of the suspension of the shield, the shells aerodynamic and collision resistance are very important. The optimal combination of the main features allows to construct a drone with a sufficient lifting capacity (thrust), flying ability and to control ability during collisions with other elements. It is necessary to determine the influence of the mesh covers on the flight properties and propeller propulsion operation, the shields and support components strength [4] as well as the behaviour of the mesh shell itself and its fixing during a collision with foreign objects. Both issues were analysed by the methods of numerical simulation using CAE. The last of these issues is the subject of this paper.

1. Design

1.1. The design of the propulsion protection

The autonomous flying exploratory robot (Figure 1-A) consists of the protection shield connected articulately with the inside parts of the drone. The main part of the drone consists of the frame which holds the propulsion system—single electric motor with contra rotating propellers, the battery set power supply, controller devices, the stabilizer and optional peripheral devices. The wind deflector covers the main part of the robot, reduces the air drag generated during flight and is an additional protection form dust and collision with objects smaller than the protection shields net mesh size. The protection net is connected with the frame with two rings movably connected to allow the rotations of the protection cover in two degrees of freedom. The protection shield is deformable to take over the clash impact without any damages. In mountings the swivel joints are axially floating according to the direction inside the protection to avoid their damages.

In other research [5] models with three different types of the protection shield to achieve the best solution from the aerodynamic and strength point of view were analysed and optimized. Multi-criteria optimization tasks do not give specific solutions. The result of the multi-criteria optimization task is the Pareto front-a set of solutions. From a technical point of view, a specific result is important, not the set of possible solutions [6]. It was decided to define the scientific problem as the single criteria task. The single optimization criteria consist of the aerodynamic features condition. The strength and modal features are treated as the constrains. The aerodynamic simulation was conducted in virtual aerodynamic tunnel, created in HyperWorks software with AcuSolve solver. The tunnel dimensions were : length 5m, height 1m and width 1m. The drone was placed in 1 m distance from the inlet of the wind tunnel and 0.7m above its bottom. Two types of aerodynamic analyses were conducted —the influence of the protection shield on the air resistance during flight with the velocity 5m/s and the influence of the protection shield on the propellers drag stream with the turbulent flow velocity 50m/s. The flow velocity was approximately calculated for a 6-inch twin blade propeller with 80% efficiency and 11.1V-12.6V bldc motor with rotations per Volt (Kv parameter) in the range from 2300 to 3650. The model was treated as symmetric in one plane. The ground was static. the standard conditions from the wind tunnel-temperature of the air 25◦C, pressure of the air 1018hPa and the density of the air 1.225kg/m3 were taken as boundary conditions. The modal analysis was conducted for the shield fixed in two opposite nodes—gimbal mounting nodes. The shield has only one degree of freedom-rotation around gimbal axis. There were calculated the eight first modes. The main idea of the modal analysis is to check if the protection shields own vibration frequency is different from the vibration frequency generated by the propulsion.The strength analysis simulation was conducted in two cases of the force applied. The force applied directly in the farthest node from the mounting and the force applied in the mounting node of the protection shield. The force magnitude used in the simulation is a constant value, calculated analytically for the case when the drone freefalls down. It was assumed that the maximal falling velocity equals 5m/s and the total mass of the drone equals 500g. This analysis allows to reject the protection shield patterns which do not comply with the minimal strength condition. The protection shield patterns that are complying with the minimal strength are further optimized. The model regarded as the optimal in the whole optimization process is used as the base of this paper. The models were created based on the existing drone with protection shield called Gimball [7]. The general shape of the shield is based on the sphere. There were three different types of the patterns which create the shields obtained in different optimization processes and manual adjustments. The protection shields topology consists of the combination of the hexagonal and pentagonal net. The best solution—the combination of hexagonal and pentagonal nets has, in comparison with the other solutions, the lower air drag, the optimal strength and as to the heaviest solution- the quadratic net, 70% lower mass. The ranges of main vibration modes of the protection cover are far from the desired propulsion vibration modes range (400-1100 Hz). The material used for modal and strength analyses is carbonfiber composite with longitudinal fiber arrangement that prevents the decomposition of the composite plies. The protection shields net beams are designed as composite rods with circular cross section. The circular cross section provides the lowest air resistance in both flow directions [8, 9]. The laminate is symmetrical, with plies orientation directions 0° 90° 0° -90°. As the fiber material is used the Kevlar 149 [10] with density 1.47 g/cm3, Young's modulus 179 GPa and Possion's number 0.36. The connections between single beams material is a thermoplastic material—Polypropylene. The carbonfiber beams ends are sunk in thermoplastic connectors. In this research only the optimal solution which fulfils the strength, modal and aerodynamic assumptions included in other research is analysed in crash test.

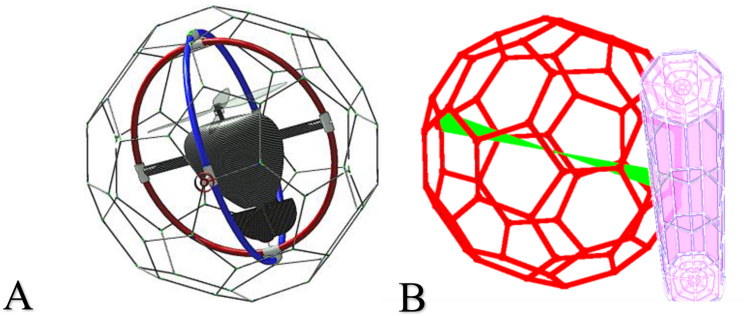

Figure 1. Geometric model of the analysed flying exploratory robot (pictured left). Geometrical representation of the numerical crash test model (pictured rigth).

1.2. The idea of the propulsion protection

Let us consider the following scenario—autonomous flying robot explores a distant planet from Earth [11,12]. The explored planet has a substantially different, not comparable to the Earth's atmosphere, usually turbulent, with local states of turbulent, difficult to predict or it includes significant thinning. The robot in its pioneering exploration mission does not have access to energy resources known on Earth, which triggers the need to ensure a positive energy balance. The research device works in extremely harsh environments. The distance to the nearest centre of human civilization in which is the explorer because of the time and quality of the responses reduces or completely prevents continuous communication. Navigating the unknown, unexplored areas in conjunction with the state of the lack of continuous link with the command centre requires its full autonomy. Due to the nature of the mission any maintenance is also not available so the ability to work in a state of incomplete performance is required. For example, the snap of one rotor blade of the propeller drive can not disable the robot. Such accident can only reduce the efficiency of the operation. Considering the alternative situation characterized by less extreme working conditions [4,11], the flying autonomous robot takes part in a mountain rescue mission. The priority criterion for rescue mission is the time to reach/find the victim. Commonly used flying devices are suitable for use in Earth's atmosphere, however, there are specific conditions disrupting the flight. Particularly in the case of flying robots with relatively low mass in dynamically changing and turbulent conditions there is a significant disorder of the flight mechanics or its prevention. Unpredictable turbulent environment, unfavourable for flight requires very rapid response of the drive to get stabilization and robots autonomy in choosing the settings for the conditions. The appliance operates in conditions in which the possibility of landing for the supplement of the power source and maintenance operations are very limited with the terrain and the ability to quickly access the device, which generates tight energy balance, requiring its drive optimization in order to minimize energy consumption [4, 13, 14].

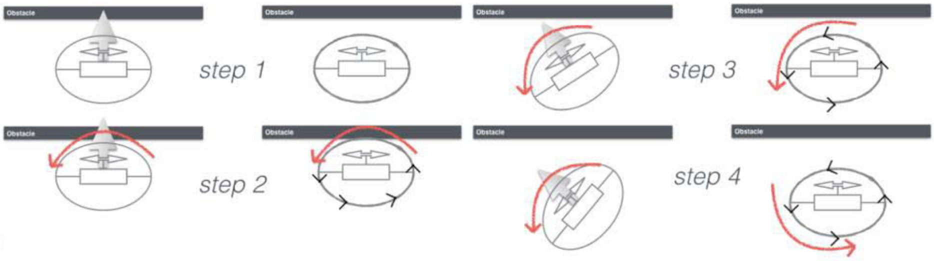

Figure 2. Visualisation of the protection shield idea.

The electrically propelled flying exploratory autonomous robot is designed for use in the turbulent and dynamically changing environment. Due to the strong need in the rescue services domain (mountain and marine rescue services) and groups working in conditions dangerous for the human's life strong and toxic smokiness, high temperature, danger of explosion or staff intoxication, the propulsion was design for the Earth atmosphere conditions. To achieve the highest energy consumption efficiency and mobility and at the same time maintaining resistance to unfavourable external influences, the main features of the propulsion system were adjusted to the usage in specified environment. To protect against the collision consequences, the static parts of the drone—the power supply, controllers, motors and extension devices as well as the rotating parts—propellers, a protection shield was designed, which covers outwardly the whole protected area. The protection shield is designed as a rigid enclosed spheroidal contoured net. To minimalize the influence of the protection shield to the flight mechanics it is mounted articulately in relation to the main part of the flying robot. The idea of pivotally mounted cover with comparison with rigid mounted cover is presented in Figure 2. The simulation was conducted in two cases. In both of the cases the drone hits an obstacle with the flight velocity 5 m/s and the protection shield works as a bumper and absorbs the hit energy. The extreme situation was analysed when the exceptionally rigid obstacle stops the drone flight. The protection shield takes over the impact of the collision. The collision reaction force is applied to the shields node. In both cases (Figure 2) the drone hits an obstacle (step 1). In the case A—for the drone with rigid mounted protection shield—the protection shield takes over the collision impact energy and forwards it with the rigid connection to the main part of the drone (step 2). The inertia of the whole flying object rotates opposite the direction of flight (step 3) and the mechanics and direction of the flight are changed (step 4). For the case B—the protection shield is connected articulately with the drone. In this case when the protection shield takes over the collision impact energy, it does not transfer it forward to other parts of the drone (step 2). The whole collision energy is damped by the protection cover and consumed on its rotation around the stable main part of the flying robot (step 3). The inertia of the drone is not disturbed and the protection shield rotation does not influence the flight mechanics or direction (step 4).

2. Methodology

The crash analysis was conducted for the best protection shield pattern achieved in the optimization process [5, 15]. The protection shield protects the main parts of the flying exploratory robot, mounted inside, from the damages caused by any collision with obstacles. The crash analysis [16÷20] was conducted in two cases—firstly collision with the mounting node of the protection shield and secondly collision with the node farthest from the mounting place. In both cases the flight direction is parallel to the ground and perpendicular to the gravity (Figure 3). The results of the collision analysis are the distributions of force value in the time domain in the mounting nodes of protection shield. Additionally, the visualisations of the deformation of the protection shield in the full duration of the contact with the obstacle and its return to the original shape were obtained. The deformations displacements visualisations are connected with corresponding von Misses shared stress distribution in the protection. The geometrical model was simplified [21÷24] (Figure 1-B) into accurate geometrical model of the protection shield and simplified model of the inside part of the drone. The simplified part of the model is designed as a point with parameters such as mass, inertia and geometrical constrains consistent with the accurate geometrical model. The mass point which simulates the propulsion system with its supportive elements of the drone is connected with the protection by constrains which allow its rotations according to the full model. The simplified mass point is described with the inertia matrix of the main part of the robot to simulate its inertial moves during the collision. The obstacle is designed as a perfectly rigid cylinder with diameter greater than the smallest gap in the protection shield and the second dimension—length greater than the dimension of the flying robot. That allows the crash contact with the obstacle over the entire length of the protection cover. According to the idea of the protection shield, the crash test simulation was conducted in the extreme case when the drone flies with the maximal flight velocity, hits the non deformable obstacle, stops the flight in the given direction and reflects from the obstacle with ability to continue the flight in different direction. The simulation was conducted in two cases. In both of the cases the drone hits an obstacle with the flight velocity 5 m/s and the protection shield works as a bumper and absorbs the hit energy.

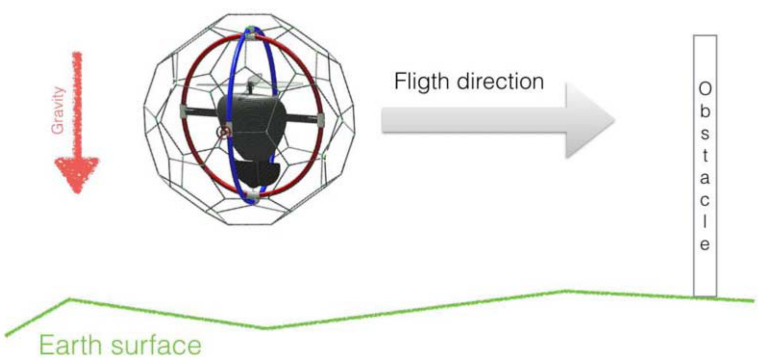

Figure 3. Visualisation of the robots reference system.

The extreme situation was analysed when the enormously rigid obstacle stops the drone flight. The protection shield takes over the impact of the collision. The collision reaction force is applied to the shields node. The gimbal is mounted in two opposite nodes. In the first analysed case the shield is hit in the node where it is mounted to the gimbal. In the second case the shield is hit in the farthest node from the mount place. The obtained results were validated analysing the mesh drop. The model was regarded as the correct one when the further decrease of the FEM mesh size does not change significantly the obtained results.

3. Results

The achieved results are the base for the strength verification of designed components. The additionally obtained results of the analysis are the visualisation of the deformation and interference of the protection shield and inside components after the collision. In the table (Table 1) the results of the strength analysis are presented. As it can be observed the net topology fulfils the strength assumptions. The von Misses stress level is relatively low in comparison with the applied composite specification. The displacements in comparison with the external diameter of the protection shield (300-400 mm) are also acceptable. The figures (Figure 4) and (Figure 5) show the visualisation of the stress and the displacements in shield with combination of hexagonal and pentagonal net pattern of the protection shield. When the mesh size is too small, which means the gaps between two adjacent beams are small, during the crash the contact surface of the protection with the obstacle is bigger. That means es that the collision force is shared more between protection shield beams and their tensions and are lower in comparison with the net with bigger gaps. However, the whole protection is mounted in two points and the forces in the mounting nodes do not depend on the shields pattern. Decreasing the protection shields mesh gaps changes the aerodynamics and increases the total mass of the protection. Due to the high sampling frequency the plots were smoothed to get clarity. The plots (Figures 6) include the force distribution in the mounting node as a function in the time domain for the analysed cases of possible collisions.

Table 1. Comparison of the results for the collisions in different nodes.

	Gimbal mounting node	**Farthest node from gimbal mounting node**
Displacement [mm]	9.12	9.463
Stress [Pa]	2.574e5	1.436e5

The results for the both cases—collision with area with protections mounting nodes and collision with the area farthest from gimbals mounting nodes can be regarded as similar. As can be noticed in comparison the plots of force distribution in mounting nodes for two opposite nodes are shifted in time domain. This shift results from the fact that the collision force was not perfectly perpendicular to the mounting nodes rotation axis which is a consequence of applying the force to one established node. In the second case the shift comes from the fact that one of the mounting nodes has direct contact with the hit obstacle and the second node is on the opposite side of the protection. At the first moment of the collision, the inertia of the main part of the drone generates pressure on the mounting node which has direct contact with the obstacle, with direction opposite to the original flight direction. Next, when the main part of the drone gets stabilization the impact of the collision is also transferred to the second mounting node. That means that the shift comes from the deformation of the protection shield and inertial displacements of the drone parts.

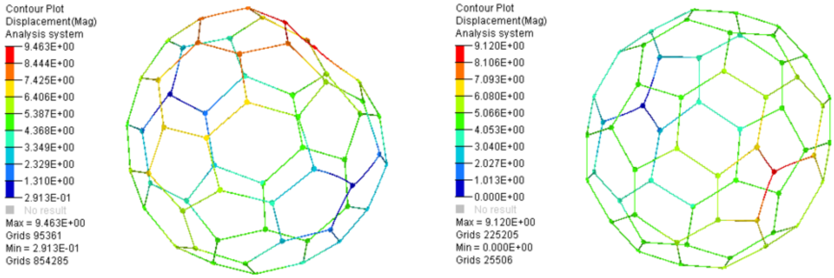

Figure 4. Visualisation of the magnitude displacements in the shield with combination of hexagonal and pentagonal net. On the left the crash force applied in the node far from gimbal mounting , on the right the force applied in the gimbal mounting.

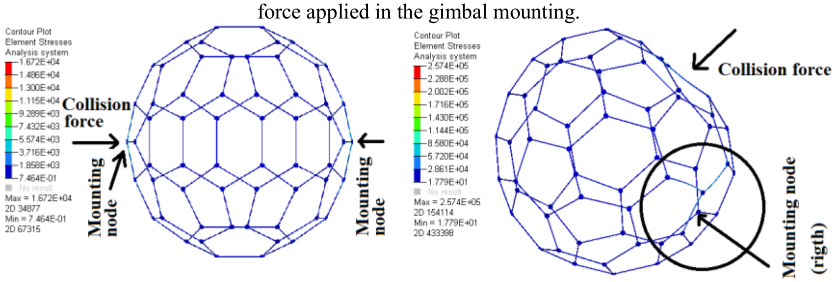

Figure 5. Visualisation of the von Misses stress distribution in the shield with combination of hexagonal and pentagonal net. On the left the crash force applied in the node far from gimbal mounting, on theright the force applied in the gimbal mounting.

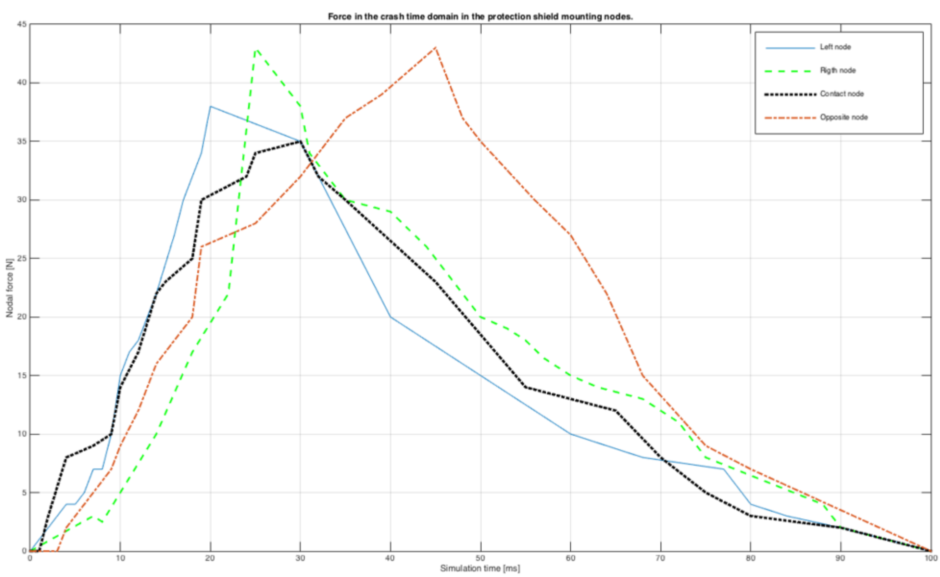

Figure 6. Nodal force in the crash time domain in the protection shield mounting nodes. for the collision with node farthest from shield mounting node marked as nodes left and rigth and the collision with shield mounting node marked as nodes contact and opposite.

According to the plots the force distribution rises up until a specified point (moment), achieves the maximal value and rises down. The force in mounting nodes rises up until the drone's velocity drops to zero—it stops on the hit obstacle for a short period of time. The second phase is the relaxation of the protection net. Due to the fact that the drone's protection shield is elastic, it accumulates the crash energy during the first phase of the crash and in second phase the elastic deformation gets back to the main shape of the protection, pushing the drone in direction opposite to the obstacle.
When the drone reflects from the obstacle the crash force acting on the mounting nodes rises down to zero. Analysing the deformation plots (Figure 4), the displacements in comparison with the external dimension and the minimal gap between the protection shield and the main part of the drone—20 mm are safe and do not restrict the rotation ability of the protection shield around the propulsion part.

4. Summary

In this paper the behaviour of protection system of flying autonomous robot's propulsion during collision with a rigid obstacle was checked. The analysed model was optimized in advance in other research. Preformed numerical crash analysis simulated probable clash situations in operating conditions characteristic for the researched drone. In both of the analysed cases the displacements (~9 mm) in comparison with the external dimension of the protection shield (300—400 mm) and the minimal gap between the protection and the mounting rings (20 mm on each side) are slight and provide a wide margin of safety. From the strength point of view, the displacements are not dangerous for the system in some cases e.g. a collision, the elastic deformation, returning to the initial state are preferred because of cushioning the impact force. From the strength point of view, the most important issue is to reduce the stresses caused in critical states—collision states. In not analysed and unpredictable cases the protection shield may break. For single collision only the epoxy warp may got broken without breaking the carbon fibres which will keep the protection shield in original shape. Broken protection, until it is not damaged or stops the propulsion, allows to continue the flight. The drive complies with design assumptions and is optimized to work under specific conditions. Using additional modifications, it is possible to optimize the drive designed under different atmospheric conditions (different from the Earth's atmosphere). Numerical optimization [21÷24] allows to obtain reliable results at the design stage, without the need for a physical model. The protection shield may also constitute a protection from freefall in situations such like absence of power or control system breakdown. The freefall case and collisions with collision force applied in different areas of the protection are the base for the future research. Another important scientific problem is the resistance of the electronic control system of the drone to overload accelerations during the collision. The acquired knowledge from the conducted research is the base for the design of autonomous exploratory drone for the missions in dangerous and unpredictable environment.

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Automated Producibility Assessment Enabling Set-Based Concurrent Engineering

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Abstract. The aero-engine industry is continuously faced with new challenging cost and environmental requirements. This forces company's, active in the industry, to work toward more fuel efficient engines with less environmental impact at a lower cost. This paper presents a method for assessing producibility of large sets of components within aircraft engines to enable a Set-Based Concurrent Engineering development approach. A prototype system has been developed aimed at enabling weldability analysis at a sub-supplier within the aero-engine industry. It is a part of a multi-objective decision support tool used in early design stages. The tool produces sets of CAD-models reaching the hundreds for different analyses, mainly focusing on performance aspects within structural analysis, aerodynamics and thermodynamics.

Keywords. Manufacturability, Producibility, Set-based Concurrent Engineering, Aero-engine industry

Introduction

An important task in engineering is to ensure that a product fulfils a wide range of requirements that are placed on it. This is one prerequisite for Set-Based Concurrent Engineering (SBCE). In SBCE a larger set of design solutions are under negotiation, with several disciplines at once. Within the aero-engine industry examples of disciplines are concerned with thermo-, aero- and structural-dynamics as well as manufacturing. Each striving to optimize the product with respect to different aspects such as performance, longevity and cost. All these disciplines are connected. For example, a change in the environmental temperature can lead to a change in structural behaviour and therefore make a change of material necessary. This in turn can lead to a necessary change in the way the product is manufactured, increasing the overall cost. These dependencies need to be analysed and visualized in a systematic way throughout the entire development process. Ultimately used to find the best trade-off.

In this paper a tool for assessing manufacturability and sustainability in early stages is presented. It is intended to be a part of a larger system to analyse conceptual designs (see Figure 1). When a parametric CAD-model of a design concept is made, the purpose is to find out how changes of the geometrical and environmental (e.g. temperature) parameters affect the performance of the concept. It is done by creating a

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multitude of variants of the CAD-model (in the order of hundreds) and environmental definitions by use of Design of Experiments (DoE). These models are then analysed using FEA and CFD software. Making all these analyses interactively is too time consuming. Instead the process has been automated so that all analyses can be run on a powerful cluster in a matter of hours or days. The results can then be reviewed, making it possible to better understand the possible trade-offs so that insightful design decisions can be taken.

This system has formerly not been capable of analysing manufacturability. As part of the work presented here, a rule-based evaluation of the manufacturability has been added. The method results in list(s) of operations which are evaluated with respect to sustainability, manufacturing preference, and cost. A case of application is presented for evaluation of the tool on the weldability of static turbine parts.

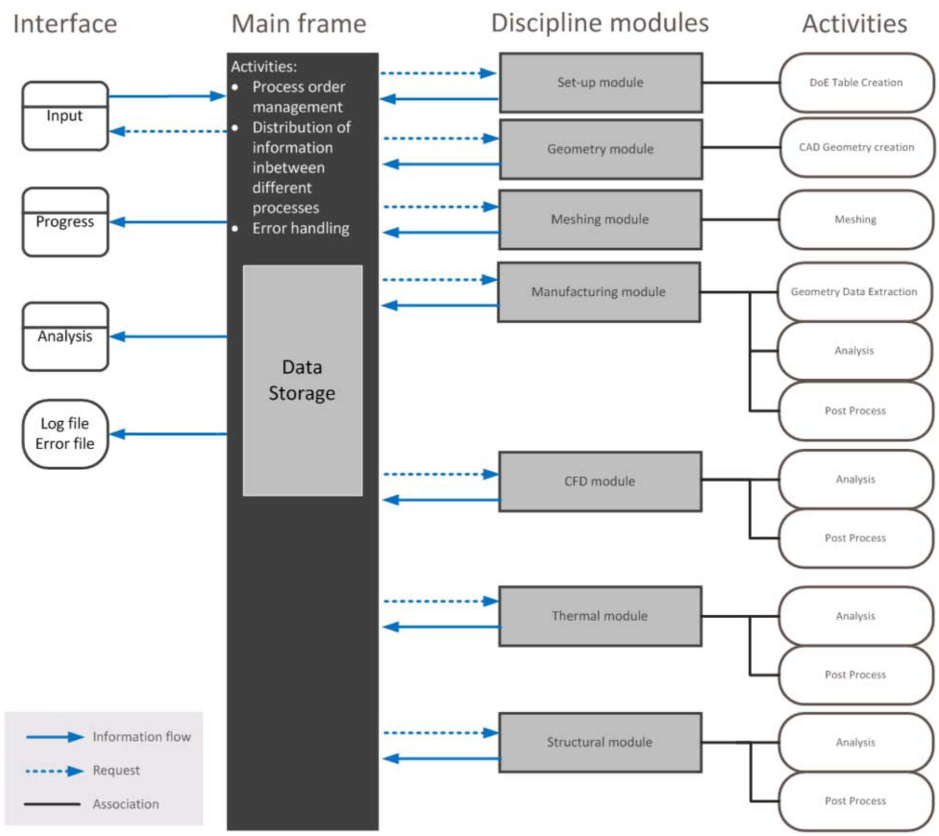

Figure 1. Envisioned future system.

1. Method

The work which this paper is based on originates from a master thesis [1]. In the master thesis the DRM (Design Research Methodology) [2] has been employed. It involved interviewing staff at the aerospace company where the thesis work was conducted to first describe the current state and then finding in which aspects to improve in consecutive descriptive and prescriptive loops. Five key employees were interviewed in this fashion; domain experts within thermal analysis (developer), parametric CAD development (developer), design of experiment (user), and computational fluid analysis (developer). Further by daily being present at the company for about six months in the spring of 2015, informal opportunities emerged to learn more about the state of practice at the company.

2. Literature

Within the field of Set-based Concurrent Engineering (SBCE), reuse of knowledge is a cornerstone [3]. Failing to reuse knowledge has also been found to hinder the positive effects of SBCE [4]. One way to represent knowledge is the use of visualization, often referred to as “visual knowledge”. There is no common definition but it is often used to describe a palette of approaches that aims at displaying complex information in an efficient way for product design and project planning [5]. Visual knowledge is also recognized as a tool to capture, communicate and document corporate knowledge [6]. One type of visual knowledge is trade- off curves, usually graphical representations of the relations between different parameters. Carefully made trade-off curves can be generic, which implies that the results can be reused in following projects. Deriving curves from experiments, human knowledge or from response surfaces leads to the build-up of knowledge of a product. It is also a source of verifying that the knowledge base is accurate since these curves can be verified by experiments. Trade-off curves and similar structured codified information obtained through systematic tests and simulations is also important in the Lean Product Development approach [5].

2.1. Manufacturability Assessment Systems

Manufacturability has traditionally been discussed from a machining point of view. Features in CAD models are identified interactively and automatically by feature recognition such that a process plan for their manufacture can be generated [7]. These process plans form the basis for planning toolpaths and making predictions on the manufacturing costs.

However, evaluating manufacturability is not restricted to automated process planning of machining. Using MAS (Manufacturability Analysis System) [8] many other aspects of manufacturability can be analysed. Manufacturability Assessment Systems (MAS) have three main mechanisms; capture, analyse and evaluate

There have been numerous attempts on evaluation of geometries for weld processes to find the cost of welding a particular geometry represented in CAD. Some examples: [9], [10], [11]. These are based on the automated or interactive evaluation of CAD-models. Ordinary CAD models only hold the geometrical information. This type of CAD models can be said to be augmented with various manufacturing information.

2.2. Sustainability

The work presented here will result in process plans for the various manufacturing operations. Having such plans enables the evaluation of sustainability, e.g. as presented in [12]. Many of the products that are designed today can be expected to be manufactured for a long time. One example is aviation, where the airframes are expected to be in use for decades. Therefore not only environmental sustainability aspects need to be taken into account but also the long-term economic and social sustainability [13].

3. Results

Through structured and informal interviews it was concluded in which aspects the CAE environment needed to improve. The number of "loop-backs" between the design and production needed to be decreased. This was planned to be addressed by introducing the manufacturability module in the CAE environment. The measurable success criteria which will be used as one part to evaluate the level of success are:

- Number of increased manufacturing constraints caught.
- Number of increased producibility metrics caught.

The final evaluation of the suggested manufacturing module is made by measuring the identified success criteria variables as well as presenting it to affected employees and listening to their feedback.

3.1. Manufacturing module

Since the manufacturing module presented here is intended to be a part of a CAE environment where hundreds of geometric models are analysed automatically the same level of automation is required. As with any automation task this requires well-structured data for the computers to work with. The main information classes utilized by this manufacturing module can be seen in Figure 2 below.

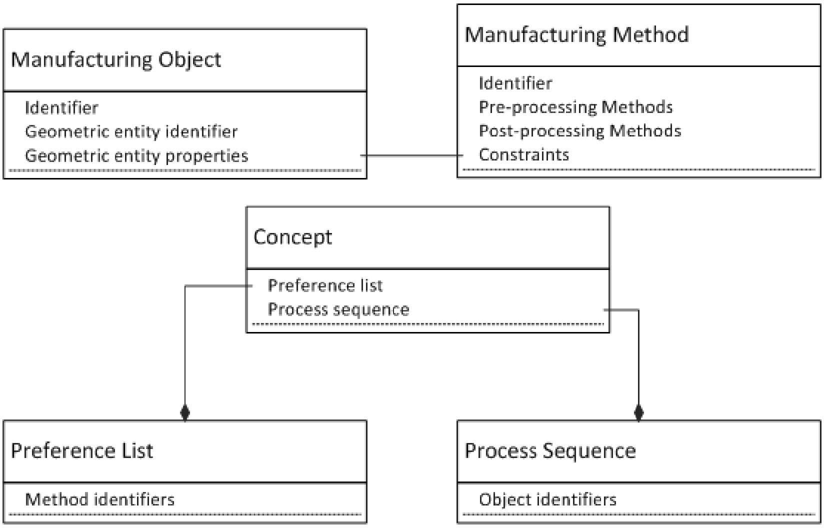

Figure 2. Manufacturing module, information classes and relations.

The five different classes are: manufacturing object, manufacturing method, concept, preference list, and process sequence. The Manufacturing Object refers to geometric entities which are thought to be manufactured. It contains two identifiers, one to itself and another to the geometric entity, as well as properties of the geometric entity.

Examples of geometric entities are edges, faces, or bodies. Properties could be as simple as weight and dimensions or data used for conducting reachability analyses. Manufacturing Method represents available operations to realize the manufacturing objects. It can be instantiated to represent e.g. weld or machining processes including its pre and post processes such as washing and deburring. Each process, pre- and post-processes included, are also associated with a number of constraints relating to the manufacturing object properties. There are also the Preference List, which can be used to denote the preference of the different methods in a particular workshop, and the Process Sequence, which describes the sequence of realising the manufacturing objects. These two can of course become extremely complex to define. One way of supporting this has been to enable the instantiation of several so called Concept-classes which can represent variations of the preference lists and process sequences, ultimately visualizing the impacts of altering them. Figure 3 below is a flow-chart attempting to aid in understanding how the information classes are used throughout the manufacturing module.

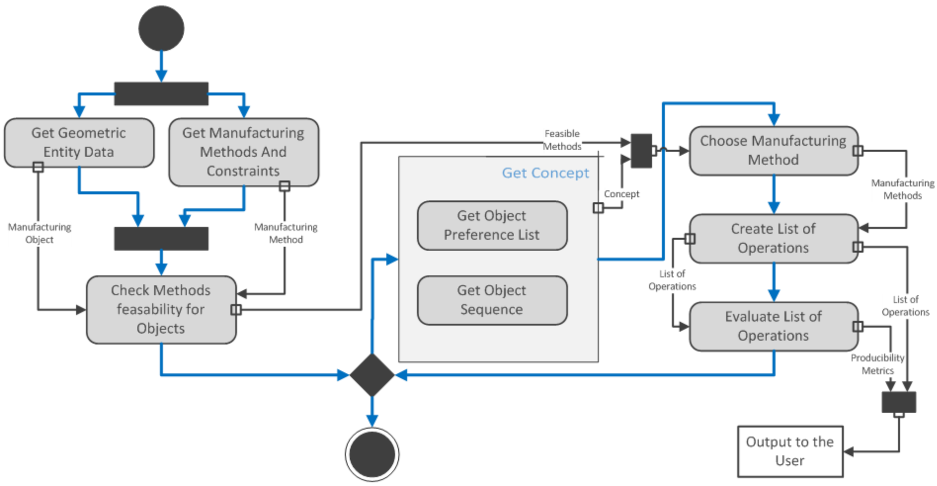

Figure 3. Manufacturing module, process and information flow

The first two actions are to *Get Geometric Entity Data* and *Get Manufacturing Methods and Constraints* which represent the geometric entities and available manufacturing operations along with its constraints, stored as instances of the Manufacturing Object class and Manufacturing Method class respectively. Once the geometric entities and available operations have been retrieved the feasibility of each method is checked on each geometric entity by evaluating if any constraints have been breached. This is the *Check Methods feasibility for Objects* activity. Each defined configuration of preferred manufacturing methods and process sequences, stored as instances of the Concept class, are then retrieved in the *Get Concept* activity comprised of *Get Object Sequence* and *Get Object Preference List* activities. These are all worked upon by first *Choosing Manufacturing Method* for each manufacturing object, which is based upon which method of the feasible ones that was highest ranked in the preference list retrieved. Followed by *Create List of Operations*, where each method is placed in the correct order defined by the object sequence retrieved. Finally, the list of operations is evaluated with respect to manufacturability and sustainability in the *Evaluate List of Operations* activity.

3.2. Test case related to welding

A test case has been applied to the welding of a static turbine part as depicted in Figure 4 below. There is a sequence for the welding often starting with building sub-assemblies as several sectors. The component consists of several cast or sheet metal parts that are welded together. These type of products have very high demands on quality. Therefore, the parts are to be inspected rigorously to detect any faults, such as cracks. The length of the service interval depends on the length of the largest crack. The parts are checked using both x-ray and dye penetrant investigations.

Figure 4. Static turbine part.

The parts and sub-assemblies are welded together using robotic welding. There are several types of welding methods such as TIG, Laser, Electron beam and Plasma. Each requires several different pre- and post-processing operations and have a number of different constraints related to:

- Access for welding
- Access for inspection
- Material thickness
- Variation in thickness
- Material combinations
- Curvature of weld

Table 1. Some constraints of the welding processes.

Process	Curvature	Thickness of plate	Material	Reachability x, y, z
Laser	min R=20	0,25mm - 20mm	Fe, Al, Ni, Ti	210, 240, 230
Electron	min R=30	0,3mm-50 mm	Fe, Al, Ni, Ti	...
TIG	min R=15	0,7mm-8mm	<List>	300, 70, 70
Plasma	min R=35	0,075mm-6mm	<List>	...

Table 1 gives some examples, some from GRANTA's CES EduPack[2] software, the actual values used are confidential.

The manufacturing module has been realized in the existing CAE environment by using the MS Excel program to manage the user input and to review the results. For controlling the program flow scripts have been written as Excel macros, Siemens NX journals, and Siemens NX Knowledge Fusion (KF) rules. The declarative scripting language KF has been used for the I/O-interface to the CAD-model. KF has been useful in that the geometric entities and their properties are efficiently transcribed directly to the Excel document. Siemens NX Journals enabled the instantiation and execution of KF rules. Excel macros were used to perform the necessary data analyses.

The KF application works by first retrieving the necessary inputs given by the user in an Excel file. In this case the inputs given were names of the geometric entities to get data from and the names of the corresponding geometric entities which could cause a reachability issue. It knows which cells to read with a user-defined Excel named range. Reachability assessments are then conducted by first projecting lines in the direction of the normal of the corresponding face (see Figure 5). Secondly checking for collision with the user specified constraining entity(s) given. Finally, if the lines do not collide, the maximum allowed angle of the lines to the entity(s) is saved for export. However, if it collided only the distance to the object is withdrawn.

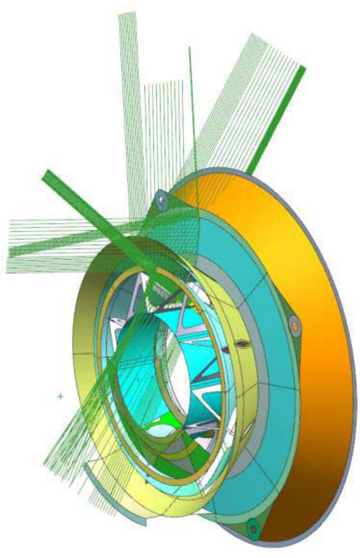

Figure 5. Reachability analysis.

What method that is finally used depends mainly on the conditions at the welding place, the possibility to access with the weld gun, and which type of joint that is required. If there are several feasible methods however the preferences differ depending on whom you ask. To enable the evaluation of different variations relating to the preferences as well as process sequences the use of "Concepts" were introduced. In this case two such concepts were defined and the difference is manufacturability could be retrieved for further analysis. Figure 6 below shows a small section of a couple of lists of operations created as a result of different concept-definitions. The first concept

[2] http://www.grantadesign.com/education/edupack/

clearly favours the electron beam welding and the second the laser beam welding. Also seen are pre- and post-processing steps such as spot welding for initial alignment, different cleaning procedures, and very important inspections.

Design-case: 27		Time of export 2015-05-11 17:47	
List of Operations		*List of Operations*	
Concept 1	**Object name**	**Concept 2**	**Object name**
SVTIG		SVTIG	
PRORAD		Lejd	
Electron beam weld	DUCT_OUTER_1_2_WELD	Laser beam weld 1	OUTER_CASE_WALL_FRONT_1_2_WELD
D1		AM1	
I1		I1	
SVTIG		SVTIG	
PRORAD		Lejd	
Electron beam weld	HUB_WALL_INNER_1_2_WELD	Laser beam weld 1	OUTER_CASE_WALL_FRONT_1_2_WELD
D1		AM1	
I1		I1	
SVTIG		SVTIG	
PRORAD		Lejd	
Electron beam weld	HUB_WALL_INNER_1_2_WELD	Laser beam weld 1	OUTER_CASE_WALL_FRONT_1_2_WELD
D1		AM1	
I1		I1	
SVTIG		SVTIG	
PRORAD		Lejd	
Electron beam weld	HUB_WALL_INNER_1_2_WELD	Laser beam weld 1	OUTER_CASE_WALL_FRONT_1_2_WELD
D1		AM1	
I1		I1	
SVTIG		SVTIG	
PRORAD		PRORAD	
Electron beam weld	HUB_WALL_INNER_1_2_WELD	Electron beam weld	OUTER_CASE_WALL_FRONT_1_2_WELD
D1		D1	
I1		I1	
SVTIG		SVTIG	
PRORAD		Lejd	
Electron beam weld	OUTER_CASE_WALL_REAR_1_2_WELD	Laser beam weld 1	OUTER_CASE_WALL_REAR_1_2_WELD
D1		AM1	
I1		I1	
SVTIG		SVTIG	
PRORAD		Lejd	
Electron beam weld	OUTER_CASE_WALL_REAR_1_2_WELD	Laser beam weld 1	OUTER_CASE_WALL_REAR_1_2_WELD
D1		AM1	
I1		I1	
SVTIG		SVTIG	
PRORAD		PRORAD	
Electron beam weld	OUTER_CASE_WALL_REAR_1_2_WELD	Lejd	OUTER_CASE_WALL_REAR_1_2_WELD
D1		Laser beam weld 2	
I1		AM1	
SVTIG		I1	
PRORAD		SVTIG	
Electron beam weld	OUTER_CASE_WALL_FRONT_1_2_WELD	PRORAD	

Figure 6. Results of the analysis.

As a result of supplying a list of operations different estimates could be established. Manufacturability preference index was one which was calculated as a result of how preferred the different methods chosen were. Cost could be approximated by looking at historical cost-results of the different operations. Sustainability metrics was being developed in a different research project depending on e.g. material choices and chemicals needed in the different processes.

3.3. Evaluation

The measurable success criteria "Number of increased manufacturing constraints caught" was increased by two, one was the maximum curvature of edges and another was related to reachability. "Number of increased producibility metrics caught" was increased by three, which are manufacturing preferred index, cost, and sustainability.

As a result of presenting the method and the prototype system to an audience varying from experts within producibility assessments, design methods, and simulations the feedback is positive but skeptical. Nobody questions the importance of enabling producibility assessments. However, they wonder about the list of preference and how it could be realized. Others gave examples of what the system did not catch; such as if several fixtures are necessary or how material deformations due to localized heat, such as in welding, is affected.

4. Discussion

A method for assessing manufacturability in early stages of design has been proposed and demonstrated through a case of robotic welding. The method enables an automated assessment of large amounts of concepts, reaching the hundreds. These large number of evaluated concepts provides the capability of providing visual knowledge in the form of trade-offs between the manufacturing discipline and others. It is essentially a MAS method specialised for the early phases of product development and large numbers of concepts providing cost, sustainability, and manufacturing preference metrics. It can provide a repeatable and quick evaluation, which if used routinely in the development process makes it possible to increase the company's capability in concurrent engineering by involving the production in earlier stages of design. The rapid evaluation of proposed design concepts can enable the company to quickly respond to requests for changes in the requirements and to predict the consequences of requirement changes. The set of different conceptual designs that can be evaluated during the same amount of time is expected to increase the possibility for SBCE. However, when interviewing the staff and incorporating the prototype system into the companies IT-infrastructure some issues emerged. It primarily involved knowledge acquisition and trustworthiness of the different metrics.

Utilising interviews of experts as the main source of acquiring knowledge with respect to rules, constraints, and available methods was time-consuming. In order to keep the tool up to date this has to be repeated regularly. Rules and constraints are expected to change over time as the production methods are continuously developed. The tool needs to be updated to supply relevant results. One interesting way of assisting maintenance as well as search of constraints could be to utilise different data-analysis approaches such as machine learning. The interviews have indicated that process "windows" exist. These windows are favourable combinations of processing parameters that can be found for certain combinations of materials and weld-methods. However, they cannot be caught and expressed as simple rules in an interview context.

The other issue involves the trustworthiness or accuracy of the metrics. In the proposed prototype system the manufacturing preference index, cost, and sustainability are used to rank the design suggestions. All analyses, in the entire CAE system, are simplified to increase analysis speed and because the information required for detailed analysis is missing in these early stages of development. However, all other modules work with well-established physical laws where the loss of accuracy is known to some extent. The manufacturing cost can change unexpectedly due to malfunctioning machines and materials cost fluctuations etc. Sustainability all the same with new discoveries regarding which materials and chemicals that affect the environment or have negative social and economic effects. Not to mention new technological solutions emerging and taking over. What basis the manufacturing preference index is based upon has not been addressed in this paper and it is partially due to its poor established definition. It might have been a product of the complexity involved. Cost and sustainability evaluations were not possible to model to a satisfactory level of accuracy at the time. The number of factors affecting these metrics were overwhelming. Being able to formalise rules which take current and future manufacturing potential as well as sustainability aspects into consideration is a tall, if not impossible, order. The manufacturing preferred index therefore enables the user to affect the weight of each method based on his intuition or tacit knowledge. It is a metric which is thought to disappear as the knowledge regarding cost and sustainability analyses is improved.

5. Conclusion

Manufacturability analysis in the early design stages is a way to increase the capability for companies to respond to requirement changes from their customers and to improve their prospects for SBCE. A method has been introduced and evaluated which extends the technology platform with rule and constraint based manufacturability evaluation. Gathering the information needed and keeping it up-to-date as well as calculating and interpreting the results has shown to be obstacles when attempting to put the method into service. Using rough cost and sustainability estimates as the only means of ranking the design suggestions is not sufficient. Streaming data from production and utilizing machine learning as a means of producing up-to-date relevant rules has been presented as one aim for future work.

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Structuring a Foundation Basis for Semantic Interoperability in Product Development Process

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Abstract. The continuous improvement of products to attend consumer needs are increasing the product development process's (PDP) complexity. This demands that systems offer support to many different stages of PDP, as much as in tangible products (physical objects) as in intangible products (services, software). Concurrently, it was identified a considerable increase in the quantity and level of detailing of the information from those systems. However, there was also an increase in the number of semantical obstacles on sharing the latter. These semantical obstacles are mainly related to the heterogenic nature of the information, which has its captured meaning interpreted in a divergent way, increasing the project costs and development time. In this context, along with the Interoperable Product Design Manufacture System (IPDMS) concept, this article proposes the development of the core ontologies from the foundation view of this new methodology, in order to aid the semantical interoperability in the Product Design stage, further improving the exchange of information during different phases of the PDP. The first stage of this research is dedicated to review the main concepts on PDP, interoperability and ontology engineering. The second stage is dedicated to the concept exploration on the creation of core ontologies and its relation to the foundation view of the IPDMS.The final stage regards the creation of the core ontologies, which will serve as basis for further development of the system and work as knowledge basis for the entire concept. This will allow an analysis on consistency and information sharing with other elements of the Product Design and Manufacture in future stages. The creation of the core ontologies was related to the development of a plastic injected product, gathering domains such as Design and Materials, that will further combine to create the product model ontology. The development of the concept can bring advantages to the PDP and increase the automation during the decision making process. This tool of support showed potential to aid the exchange of information and inconsistency analysis at the product development process in the future, allowing risks reduction and rework at advanced project stages, also remarkably reducing time and total project costs.

Keywords. Product Development Process, Transdisciplinary Engineering, Semantic Interoperability, Formal Models.

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Introduction

Currently, the demand for more elaborated products, which are developed in less time and with higher quality associated with the continuous improvement of technology, has increased the complexity in the product development process (PDP). Therefore the need for computational systems that offer support to the many different stages of the product development and can also share the knowledge produced between these stages and the products manufacture [1].

There has been a considerable increase in the quantity and level of detailing of the knowledge from these infrastructures. However, there was also an increase in the number of semantical obstacles on sharing it efficiently. These semantical obstacles are mainly related to the heterogenic nature of the knowledge, which has its meaning captured and interpreted in a divergent way by the many different departments charged with the PDP, increasing the costs and development time [2].

There are several solutions to enable interoperable knowledge share, however this article will focus in the adoption of a direction where the meaning, in computational form, associated to core feature-based design and manufacturing concepts is established. This method uses formal heavyweight ontological structures to define the meaning behind the information [4][5], such as standard features, and machining process execution knowledge. Although there has been a range of work that has focused on foundation ontologies [6][7], the scope of these foundation ontologies has remained relatively broad.

A mutual understanding of the semantics inside the shared and exchanged knowledge representations is the cornerstone in the quest for semantic interoperability [8]. So in this context, it is proposed the structuring core ontologies as a foundation bases to aid the product development process. These ontologies will offer semantic capabilities from which new ontology based models can be specialized. Therefore, ensuring that knowledge created in one knowledge domain of the product development will be shared and understood in another domain without ambiguity.

This research focus on the creation of the foundation view ontologies for the Interoperable Product Design Manufacture System (IPDMS), which is the first step to ensure a true multi domain knowledge share environment through knowledge formalization.

1. Literature Review

The literature review regards an analysis on concepts such as Product Development Process (PDP), interoperability and ontologies. The following review focus on the advantages and limitations of the researched topics, as well as their stablished relations.

According to [9], the PDP can be defined as a set of multidisciplinary activities focused on the creation of a product, taking in consideration customers' needs, technological viability and market opportunities. This definition basically, lays on the knowledge sharing and communication between developers as key factors for success. However, the different knowledge domains result mostly in creation of data misinterpreation, ambiguity, semantic inconsistencies and mistakes, remarkably in design and manufacturing stages[10], which represent the higher costs in PDP [9].

Interoperability, as defined by [11], is an improvement in communication between two heterogenous systems, as a way of optimizing their joint operations and resources sharing. [12] and [13], further explored on its application, stating that semantical issues are the main reason why interoperable systems does not work. [12] reinforced that semantical interoperability is a key factor in the development of those systems, defining the term as the ability of computational systems to jointly interpret and share the meaning of concepts in multiple applications.. The development of those systems demand highly integrated solutions, with solid and formalized semantical basis [14]. In this context, structuring formal ontologies has proven to be a feasible solution on sharing formalized information, providing increased knowledge in many domains of application [15].

In engineering, the concept of ontology was significantly refined in the past decades. Originally, [16] defined it as an explicit specification of an abstract concept from reality. [17] defined the concept as a formal and shared understanding of selected knowledge domains that specify concepts and relationships for a determined number of agents. [5] emphasized that an ontology consists in a model or representation that "provides a basis for sharing meaning". The definition used in this paper, a synthesis of previous works, is that an ontology is characterized as a formalized model that represents an abstraction of reality that provides a basis for knowledge sharing.

Ontologies can be characterized by their content. The ones focused on taxonomy, basic relations and that are, mostly, readily understood are characterized as lightweight onotologies. There are also ontologies that present the lightweight structure, but are enriched with constraints that work as axioms in order to clarify the meaning behind the shared knowledge and information, those being called heavyweight ontologies [4]. There are problems with the application of ontologies as well. Currently, their use has limited applications, and it presents issues when associated with other knowledge domains [18]. To improve this, new systems were created, focusing on semantic interoperability among transdisciplinary fields of knowledge. [19], for example, developed the Interoperable Manufacturing Knowledge Systems (IMKS), a concept that would facilitate the implementation of an interoperable knowledge basis to assist in the development of new products by the conceptual integration of different domains.

This work gathers the concepts of PDP and ontology, as means to achieve the structure of core ontologies to be used in an interoperable environment. The main goal is to define the knowledge basis that will be used to extract and refine information, improving communication between PDP phases and contributing to a more integrated transdisciplinary environment in order to fulfill customer's expectations.

2. Research Concept

2.1. Overview

The activities of PDP gather considerations of a significant number of knowledge domains, taking a varied set of opinions from developers. As mentioned in section 1, there are several limitations and problems related to data misinterpretation generated by semantic obstacles, which can elevate costs and impair further development stages. Those errors create a necessity to formal knowledge sharing between different systems [20].

The concept of semantic interoperability can be considered as a solution to communication and information sharing process. Allied to the formal structure of ontologies and new methodologies, it is possible to achieve improved results during product development stages. The Interoperable Manufacturing Knowledge System [19] is one of the current strucures created to provide an increased integration to the conception of new products, but it is approach is limited to a more conceptual view.

In this context, a new system, currently on development, was conceptually proposed, the Interoperable Product Design and Manufacturing System (IPDMS) [21], which would support information and knowledge exchange in computer environment to support PDP. The IPDMS work as a system that would clarify specifications in order to analyse inconsistencies by consulting and sharing information, this way improving semantical interoperability across PDP. Briefly, it would technically perform by using core ontologies to create specialized heavyweight ontologies. Further, there is a semantical reconciliaion that is responsible for keeping data standardised. The system would use this information along with clients' requirements, that will impose constraints to the specialized ontologies. The information obtained through reasoning is used to make CAE systems interoperable, increasing quality during development and preventing mistakes by warning the developer of inconsistencies in information.

The conceptual model uses core concepts and constraints to develop the information in the application view and link with the semantic reasoning rules of the ontologies. The architecture of IPDMS is composed by four perspectives: (i) Foudation View; (ii) Application View; (iii) Semantic Reconciliation View; and (iv) Constraints View. IPDMS focuses on the knowledge exchange through the specialization and semantical mapping that uses core ontologies as basis. The system is based on the IMKS developed by [19], but it brings a new view by adding practical implementation on development tools. This research focuses on the creation of the core ontologies of the Foundation View as it is the first pillar to support the development of the system.

2.2. The Foundation View

A set of core onotologies composes the Foundation View (FV) of the IPDMS. This section of the system is heavily based on the IMKS model [19], but its further application will turn out to be more practical along with virtual product development tools. The FV gathers a host of information from real world and represents a high level abstraction of different domains through models. There are many core ontologies present in this view, such as the Design Core, Materials Core, Manufacturing Core, etc. These cores represent information and process semantics, showing relations between entities and processes. To structure this view, firstly, there is a creation of an UML diagram, just to conceptually define the ontology. Secondly, a lightweight ontology is structured, in order to define classes and their primary relations. Finally, in order to further specialize it, semantic processes are added, turning the former lightweight into a heavyweight ontology through the creation of rules and constraints (Fig. 1).

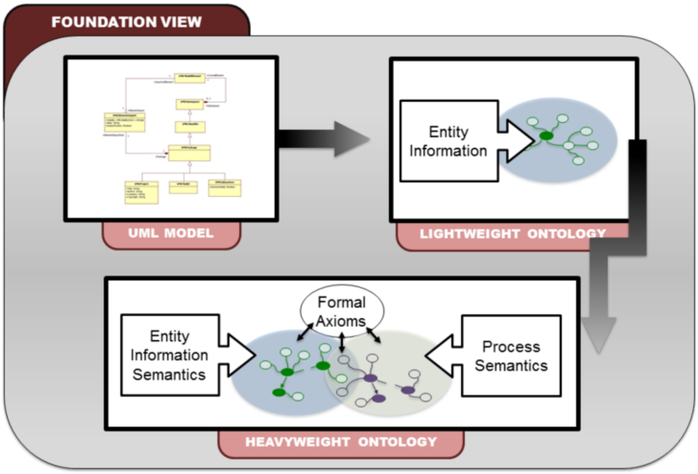

Figure 1. Foundation View Model.

According to the procedures defined by [22], these ontologies were structured in the Protégé [23] software, an specialist interface to define entities, relations and even reasoning rules, among other applications. Protégé is a tool developed to structure ontologies, using as standard the Web Ontology Language (OWL)[24]. To develop the semantic rules and constraints , the Semantic Web Rule Language (SWRL) [25] was used. In the IPDMS, these ontologies are basis for new specialized ontologies, that will also be written in the OWL language to avoid semantical impairness.

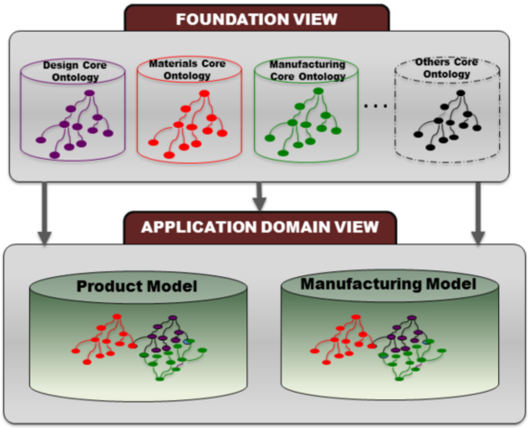

Figure 2. Specialisation of Core Ontologies.

In this context, Fig. 2 illustrates the information specialisation from the core ontologies to new specialized, product focused heavyweight ontologies. In the IPDMS, the product models are information models that regard the development of a single product. In this research, a plastic injected model was taken into analysis. Mostly, products of this type are severely impacted by the design and choice of materials (higher costs).

3. Applying the Foundation View in a Case Study

This section highlights the structuring and analysis of the core and specialized ontologies which makes the IPDMS. This system uses four core ontologies, which can be regarded as lightweight or heavyweight ontologies.

The core ontologies represent different domains which have to be considered during the product development in a design for manufacture environment. These domains are: i) Design, this ontology formalizes the product design knowledge relevant to the stages of PDP; ii) Materials, here is formalized the materials that can be used to develop a new product with its properties; iii) Manufacture, the formalization of the manufacturing processes the raw material will suffer to become the product alongside the variables which affect each process; and iv) Tolerance, this ontology formalizes the knowledge of dimensional and geometrical tolerance in various standards.

The information collected to stablish the foundation view for this research was related, as a particular case, to the injection moulding of a plastic cup in Fig. 3, which takes in consideration shrinkage rate, design tolerances, manufacturing standards, and other factors.

Figure 3. Injected Plastic Cup.

The core ontologies were structured using as knowledge base the semantic mapping and structuring of different authors. These semantic structures were then formalized into a particular core onthology. These semantic structures were chosen to be used as core onthologies since the knowledge contained were already validated. That is, the knowledge representation was already proved to be usable representation of the reality.

The core ontologies in the IPDMS don't contain any individuals, as those are generical ontologies. These ontologies, also have common elements, which show the relationship between these different domains. Thus, it can be used to create an interoperable environment which will aid the knowledge share of each new project.

This environment is made possible through a project specialized ontology and is created through the union of the projects relevant knowledge of the four core ontologies. The specilized ontology will also be able to analyse inconsistencies as well as share and consult the projects information. The aim of these ontologies is to, in future applications, serve as a knowledge basis for an interoperable environment that aims to join domains and serve as an alternative to the linear approach of PDP.

This article will focus on the structuring and validation of the materials and design ontology as in these are contained the critical knowledge for the whole product development process as they will define the possible manufacture processes and cost of the PDP.

The Design ontology was structured using the semantic mapping developed by [24] (Fig 4). In this mapping the author creates a feature system where all the product defining information is classified as Primary Feature, Transition Feature or Modifying Feature. The primary features are the most important as they transmit the geometry, dimensions that the product has, it is with this information that the product model ontology will be start to be created. The transition features connect two primary features and the modifying are technological features, such as holes that could not be transmitted with the primary or transition features. The ontology structure is shown on Figure 5.

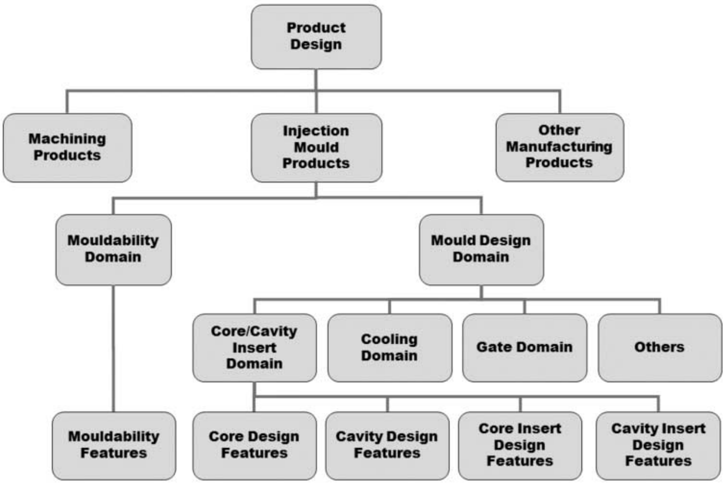

Figure 4. Simplified UML Diagram for the Design Ontology Adapted from Canciglieri [26].

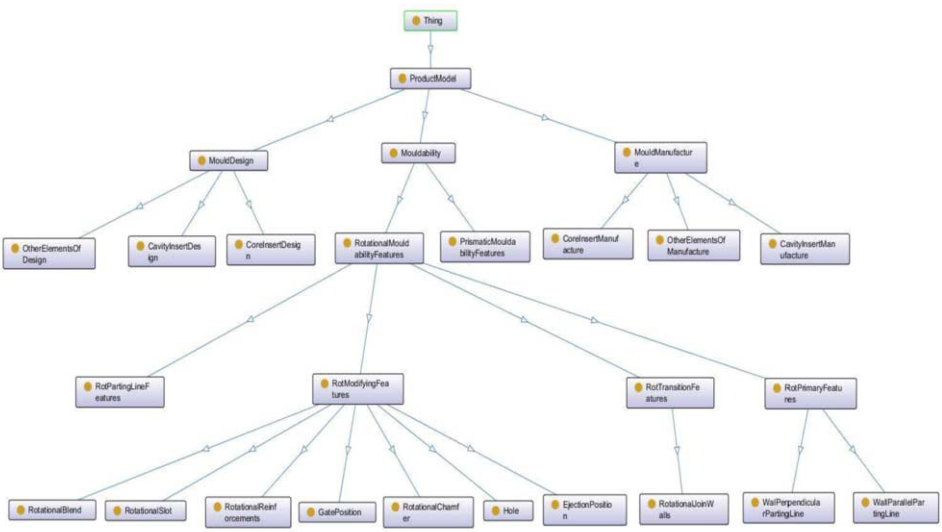

Figure 5. Design Ontology Structure.

The materials ontology formalizes and classifies the materials that can be used to develop a new product alongside its properties. This ontology was created using as knowledge base the work from [27] (Fig 6) and aids in the manufacture process decision making as it gives crucial information to the user. The structure of the materials ontology is shown on Fig 7.

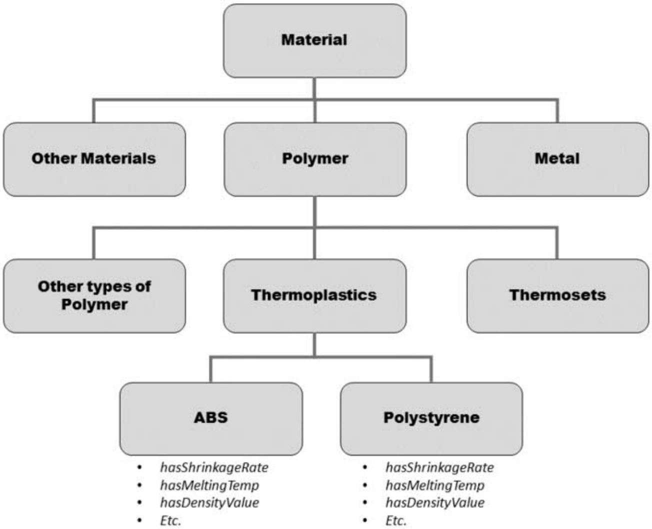

Figure 6. Simplified UML Diagram for the Materials Ontology Adapted from [27].

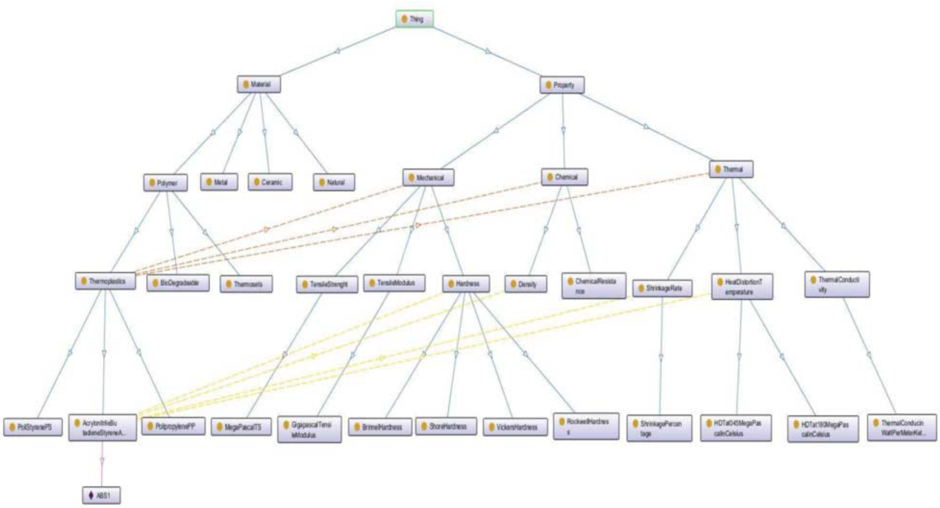

Figure 7. Materials Ontology Structure.

4. Results Analysis

The main results obtained in this research was a concept of the foundation view of the IPDMS, through the formalization of information and creation of core ontologies. The created ontologies serve as a knowledge-basis that will be further refined in the system.

The new ontologies can offer a basis for the development of several new products, just depending on which information will be used from each core. The information can also be refined and further improved, to better attend the developer's needs. This brings a new application to the ontologies and, consequently, extends its use. The use of already-existant semantical structures to the ontologies made the process of creation easier, but it is stil necessary to analyse its semantical structure in later stages.

One of the achievements of this research is the reusability of the core ontologies structured. Different products will be able to use it through their development in the future, being a significant mark to the development of the IPDMS. Individually, the ontologies can bring significant improvement in decision making, by working with the formal structure of different domains. By performing an analysis, the core ontologies of the foundation view might bring some reflections on PDP, aiding on the overcome of semanticle obstacles and claryfying the specifications of the product,by this improving the semantical interoperability and reducing costs and mistakes across PDP.

5. Conclusion

The use of core ontologies in the IPDMS is a viable way to represent the reality of the PDP systems in a way where the knowledge created in each new project can be added and reused to better the quality of the new product, reduce the time and cost of its development. It has shown also the flexibility that the development teams need in the knowledge formalization process, being capable of ensuring that all the diverse knowledge domains that exist in a PDP team are inserted into an application, shared and understood throughout the different stages of development and areas of knowledge.

However, it presents risks, the core ontologies must be created alongside specialists as to ensure the validity of the ontology. If the knowledge presented in a core ontology is not validated, that is, if the knowledge inserted inside the core ontology does not represent a good abstraction of reality, it can generate misleading information in the PDP which can, in turn, cause an increase in the time and cost of the project and lower the final products' quality.

Through the use of the product model ontology, the knowledge share and understanding between the stages of the product development and its manufacture can be ensured and based for the semantic mapping needed for the creation of an ICT. This is possible because even though this ontology is specific for each project, it derives its knowledge from the core ontologies, which can be reused. The knowledge in the IPDMS flows both ways, from the core to the specialized and from the specialized to the core.

As the IPDMS is in current development, the next stages are the development of an application which will control the creation of the product model ontology and instantiate it and integrate this application with a CAD/CAM environment.

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Particle Size Distribution Correction Method Using a Simulated Annealing Technique

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Abstract. The procedure for obtaining the particle size distribution by visual inspection of a sample involves stereological errors, given the cut of the sample. A cut particle, supposedly spherical, with radius R, will be counted as a circular particle with radius r, r≤R. The difference between r and R depends on how far from the center of the sphere the cut was performed. This introduces errors when the extrapolation of the properties from two to three dimensions during the analysis of a sample. The usual method is to correct the distribution by probabilistic functions, which have large errors. This paper presents a method to reduce the error inherent to this problem. The method is to compute a simulation of the preparation process in a sample whose structure can be described by non-penetrating spheres of various diameters which meet a known probability distribution function, for example, a log-logistic function, or even a constant function. For each distribution radius, a number of spheres is generated and virtually cut, generating a bi-dimensional (2D) distribution. The 2D curves of the spheres distribution obtained in this simulation are compared with that obtained by the experimental procedure and then the parameters of the threedimensional distribution function are adjusted until the 2D curves are similar to the experimental one using the optimization method Simulated Annealing for the curve-fitting. In future this method will be applied to the analysis of the oil reservoir rocks.

Keywords. Simulated annealing, Porous media, Curve-fitting, Stereology

Introduction

The stereology is a interdisciplinar study field which aims to evaluate the three dimensional (3D) properties of a sample using a material bidimensional (2D) information. Several geometrics and statistical methods are applied to achieve this target [1].

The stereology has many applications in several sciences, as biology, medical sciences, material sciences, and wherever it is necessary to obtain information of dimensions higher from samples with inferior dimensions. The common stereology challenge is to understand the structural inner three-dimensional arrangement based on the analysis of the structure slices that show only two-dimensional information for that stereological principles take into consideration geometry and probability statistics [2].

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It is inherent, however, to the stereological technique, the introduction of errors during the extrapolation process. Garcia *et. al*. [3] state that A major problem of sampling/slicing is the loss of dimension; a 3D object becomes a 2D area, a surface (2D) becomes a line (1D), a line (1D) becomes a point (0D) and a number (points 0D) is lost. A stereological approach provides solutions to this.

In the last 50 years, stereological studies have appeared in literature more and more frequently, the first studies being based on pioneers [4], [5], [6], [7], [8]. The so called "new stereology" was developed in the XXth century's eighties, a collection of procedures turning stereology easier and more unbiased [10], [11] - in reality, the question of bias and stereology is still under discussion, but new techniques make stereology more consistent [12], [13], [14], [15], [2].

On the other hand, the idea of estimating stereological parameters from optical sections within a thick slice was first used for counting particles in optical disector principle [16] and in unbiased sampling brick rule [17], and then in many other stereological methods, e.g., nucleator [11] and planar rotator [18] applied to a stack of optical sections and estimating the mean particle volume, spatial grid [19], methods for estimating the surface area, method of vertical slices [20], and global spatial sampling [21] used for the length estimation.

Indeed, stereology is dynamic and full of perspectives for the future, new approaches to old questions still stimulates stereologists to test possibilities, an exciting example is the Simulated annealing technique for curve fitting.

This research evaluated several functions as candidates to represent 3D particle size distributions which generated 2D particle size distributions experimentally measured through rock samples cut and image analysis.

The evaluation determined the most adequate function for representing the particle size distribution and a new alternative was also proposed: not using a specific function, but to optimize a constant distribution.

1. Methodology

The experimental procedure to obtain a particle size distribution was the same as [22]. A typical particle diameter distribution can be observed in Figure 1.

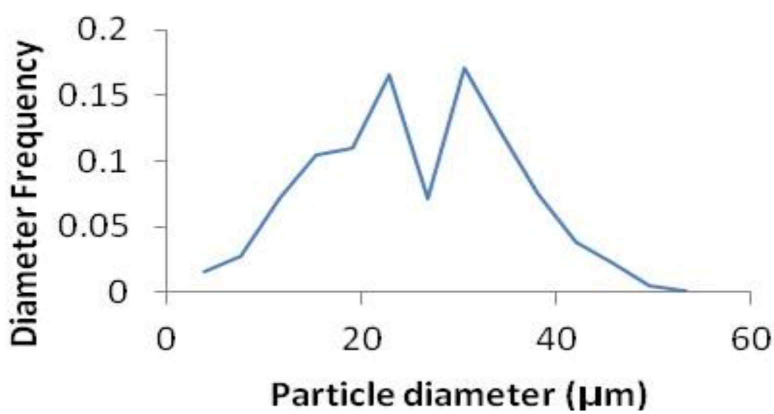

Figure 1. Typical particle size distribution for a sandstone sample obtained by image analysis.

1.1. Particle size distribution modeling

To model a particle size distribution, it was done some considerations:

- each particle is represented by a sphere;
- the spheres are non-penetrating;
- the 3D particle size distribution follows a known unimodal distribution, as a log-logistic function with unknown parameters which shall be optimized by a Simulated Annealing method;

These considerations aim to make the sample particles model as real as possible, but yet feasible to optimize. The unimodal function consideration intends to simplify the optimization procedure, even if the Figure (1) can be considered a bimodal function, it is considered that the oscillation around the 30μm diameter is a fluctuation.
The functions chosen to model the particle size distribution were the following:

$$f(x,\mu,\sigma)=\frac{1}{x\sigma\sqrt{2\pi}}e^{(\ln(x)-\sigma)^2/2\sigma^2} \tag{1}$$

$$f(x,\mu,\beta)=\frac{e^{\left(-\frac{x-\mu}{\beta}\right)}-e^{\left(\frac{x-\mu}{\beta}\right)}}{\beta} \tag{2}$$

$$f(x,\beta,n,\delta)=\beta e^{-\beta(x+\delta)}e^{-ne^{-\beta(x+\delta)}}\{1+n[-e^{\beta(x+\delta)}]\} \tag{3}$$

$$f(x,\alpha,\beta)=\frac{\left(\frac{\beta}{\alpha}\right)\left(\frac{x}{\alpha}\right)^{\beta-1}}{\left[1+\left(\frac{x}{\alpha}\right)^{\beta}\right]^2} \tag{4}$$

These functions, Log-Normal – Eq. (1), FischerTippet – Eq. (2), Shifted-Gompertz – Eq. (3) and Log-Logistic Eq. (4), were chosen as unimodal functions and due to its flexibility. The log-normal function, for example in Figure 2 for different values of σ, can have several shapes, depending on the variables.

For all these functions the function parameters were randomized and a 3D initial particle size distribution was generated.

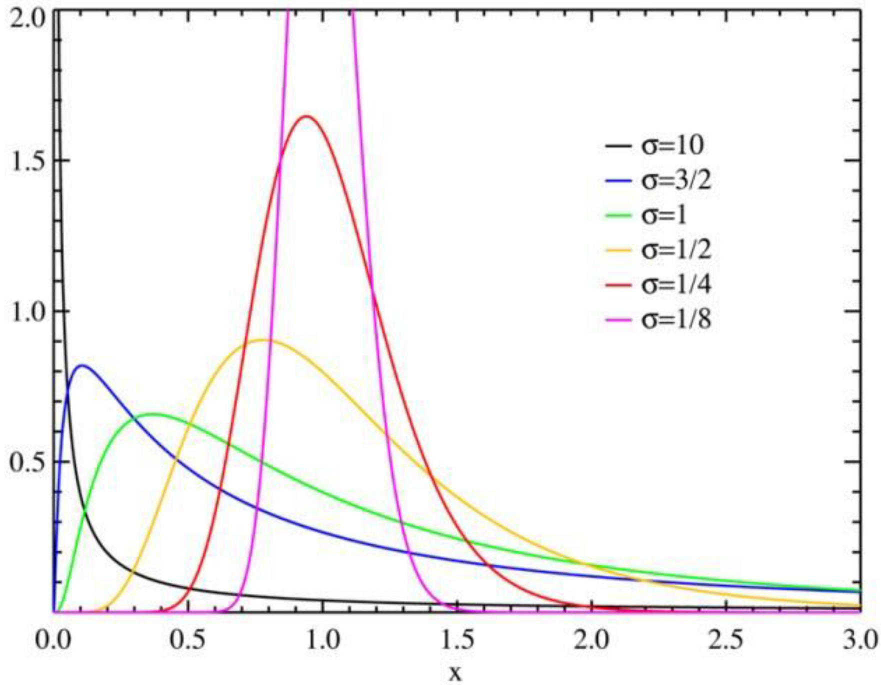

Figure 2. Log-Normal function shapes varying the σ parameter.

The 2D particle size distribution was generated through virtual sphere slices. For each distribution radius, a number of 10^5 times the distribution spheres was generated. These spheres are then cut and 2D particles (circles) with smaller radius are then created, as shown in Figure 3. R is the real radius, r, the measured radius and h is the distance from the center where the slicing plane cut the particle. For example, a particle size distribution which has 0.01 (1%) of its particles of radius 3, will have, for this radius, 1.000 spheres generated, which will be virtually cut and these cuts can create 2D particles measurements with radius 3, 2 and 1.

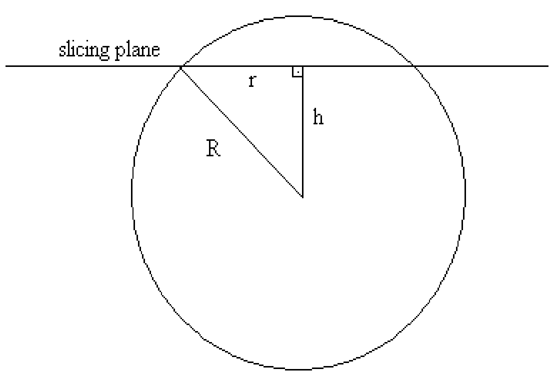

Figure 3. Sphere (Particle) cut by a slicing plane illustrating the measurement of a r radius, smaller than R.

Both the 2D particle size distribution created by a 3D particle size distribution can be observed in the Figure 4 for a Log-Normal distribution. As expected, the created 2D curve has a higher frequency of particles with smaller diameter than the 3D curve.

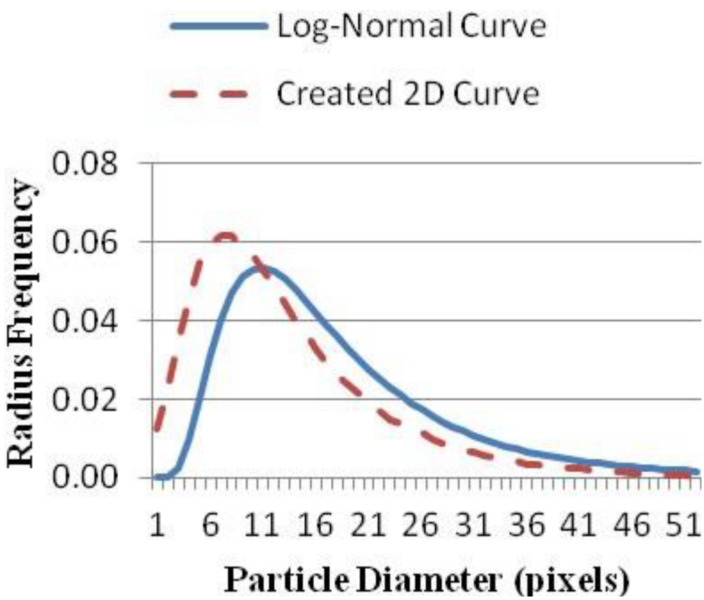

Figure 4. Log-normal curve and the created 2D after the virtual cuts.

1.2. Simulated Annealing (SA) Algorithm

The well-known SA technique [23], [24], [25], [26], [27], [28] [29], [9], [30] was used to optimize the 3D particle size distribution.

Once the 3D particle size distribution is generated, a SA algorithm is used to adjust the curve parameters to fit the 2D gran size distribution. The sequence of steps to optimize the curve is described below:

1. generate a 3D particle size distribution with random parameters;
2. execute a virtual slicing procedure, generating a 2D particle size distribution;
3. compare the experimental and generated 2D particle size distributions, calculating a square error;
4. modify the 3D particle size distribution parameters and accept or reject the modification according to the SA algorithm;
5. go to step 2 until convergence or iteration limit is reached.

Notice that the optimization is carried on two levels. While the 3D curve is directly modified, the 2D generated curve provides the square error. This configuration is due the experimental procedure, which provides a 2D particle size distribution, so it is necessary to compare both 2D distributions. The square error was calculated as the equation (5):

$$\mathbf{E} = \left[\sum f(r)_{gerada} - f(r)_{2D-Experimental}\right]^2 \quad (5)$$

The SA algorithm used in this research is the classical algorithm with linear cooling schedule, having $T_{c+1} = 0.99 \cdot T_c$. The cooling happened after 1000 well succeeded iterations.

The parameter modification was executed at one parameter per iteration. For the Log-Normal function, for example, if the t iteration modified the μ parameter, the t+1 iteration modified the σ parameter. The modification step was 0.01 and it could be added or subtracted with 50% of chance for each option. The convergence target was 10^{-3} for the square error. The iteration limit was 10.000 iterations without improvement in the energy function (square error).

The technique cost less than one minute to optimize a curve using an Intel® i3 2.33GHz processor.

2. Results and discussion

A typical result for the same particle size distribution from Figure (1) can be observed in Figure 5. The square error for this result was 9×10^{-4}.

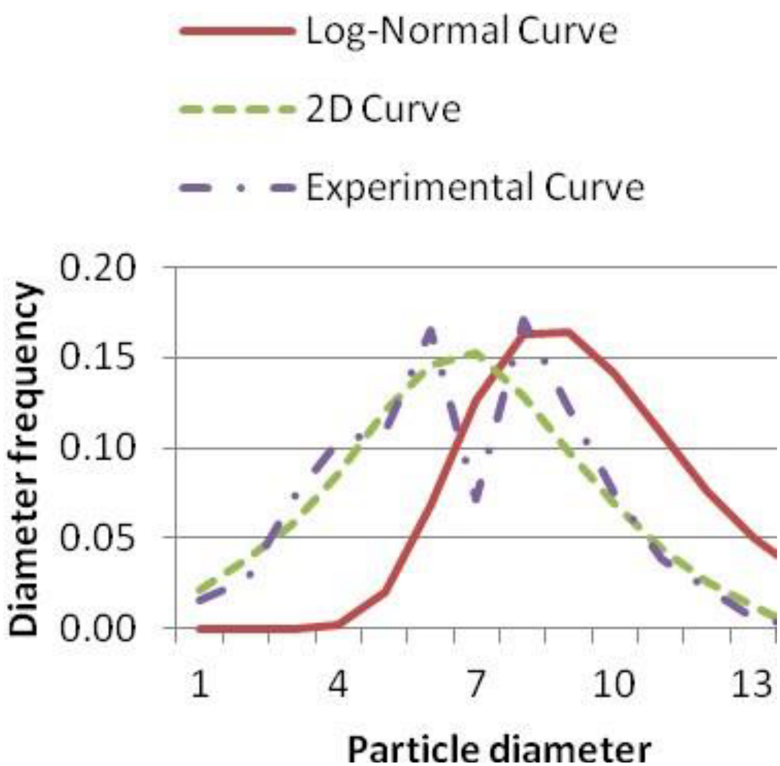

Figure 5. Processing result for the particle size distribution exposed in Figure 1.

To test which function could model better the particle size distribution, a SA process was executed for 21 particle size distributions for all the adopted functions without ending the processing with the convergence criteria. An average square error for all the samples can be observed in the Table 1. The function with the best result was the Log-Logistic. The obtained square error was 7.63E-04. This indicates that the best function for representing the particle size distribution among the analyzed functions is the Log-Logistic.

Table 1. Average square error for all the 21 rock samples processed without convergence criteria stop.

Function	Average square error obtained
Log Normal	1.03E-03
Shifted Gomperz	8.56E-04
Fisher Tippett	8.14E-04
Log Logistic	7.63E-04

To compare the proposed methodology with classic methods, a Log-Normal distribution with 10 particle diameters, μ=1.3 and σ=0.4 was adopted as a 3D particle size distribution and the virtual cut was executed. The resultant distributions are shown in Figure 6.

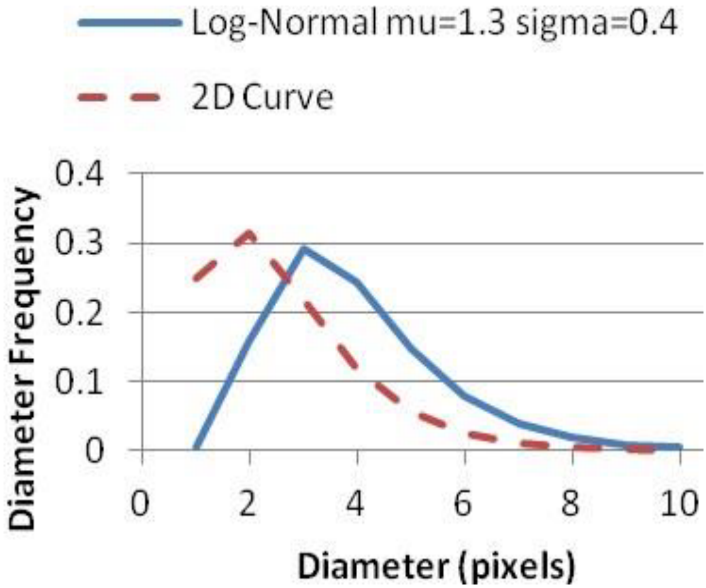

Figure 6. Log-Normal curve with 10 particle diameters, μ=1.3 and σ=0.4 and 2D curve resultant from virtual cuts.

The classical method of Schwarz-Saltykov [1], which could be adapted for a curve correction, was applied to the resultant 2D curve and a 3D corrected particle size distribution was generated. The latter was compared with a particle size distribution generated using the proposed methodology through quadratic error calculated in the 3D distribution. The corrected distributions and the resulting curves are disposed in the Figure 7. The quadratic error for the Schwarz-Saltikov method was 2.2E-1, while the function SA was 8E-2, approximately 5 times smaller error.

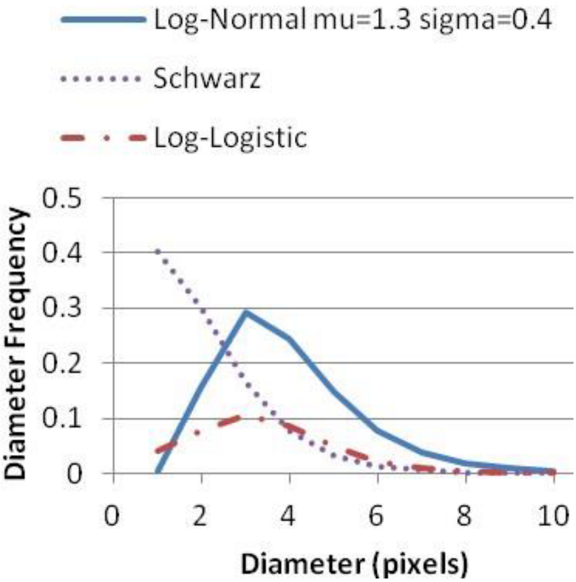

Figure 7. Comparison between 3D particle size distributions generated by the proposed methodology and the classical Schwarz-Saltikov method.

It is remarkable that even if the error was almost 5 times smaller, the 3D distribution was not satisfactory. The function SA was not able to represent a Log-Normal curve with a Log-Logistic curve, even if both distributions are theoretically compatible.

A proposed solution is to not use a function to represent the 3D particle size distribution. Instead, it can be used a constant function or a linear function and let the SA algorithm modify it freely. A preliminary result of a constant function modifying with modifying step 1E-3 is shown in Figure (8). The 2D input was the same 2D Log-Normal as the previous example and the 3D result is compared with the previous Log-Normal.

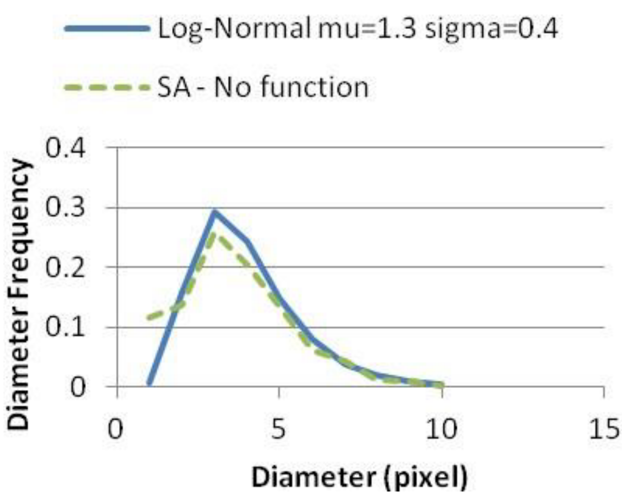

Figure 8. Comparison between 3D particle size distribution: generated by the SA-no function and previous Log-Normal function.

There is a significant agreement between both functions. The quadratic error for this methodology was 1E-2, even smaller than the SA with a function representation. This methodology was also tested with the gran size distribution showed in Figure 1. The resulting curves are exposed in Figure 9.

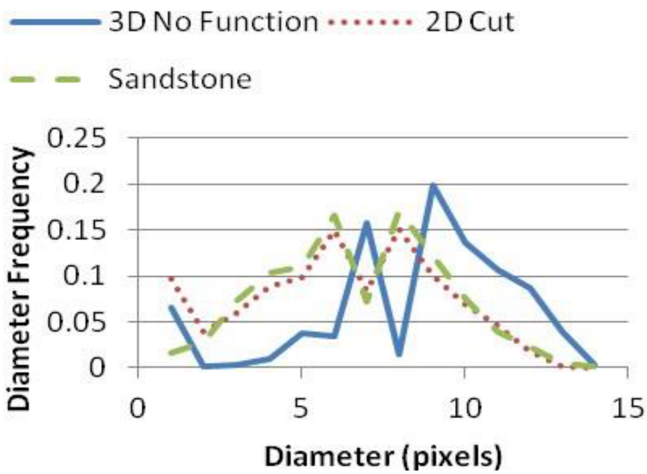

Figure 9. 3D Curve generated using a SA technique without optimizing a specific function and its 2D cut comparing to a sandstone grain size distribution.

An interesting fact is that the new methodology was able to reproduce a bimodal function and the 3D generated curve was also bimodal. This new methodology shall be further investigated.

3. Conclusions

It was proposed a new methodology to model particle size distributions. A SA algorithm was used to fit a 3D distribution with virtual cuts and minimizing a 2D function, comparing this latter with an input grain size distribution obtained experimentally.

It was tested 4 distribution functions, LogNormal, Fischer-Tippet, Shifted-Gompertz and LogLogistic. The function which had best performance was the Log-Logistic distribution, yet, in a simple test of flexibility, it was clear that the performance of the function fitting was not adequate.

A solution was proposed, which is to use a SA algorithm to fit freely a constant function. The preliminary tests showed that this algorithm was able to reproduce both a 3D Log-Normal function and a bimodal input function, indicating that it can be used to represent 3D particle size distributions determined from 2D particle size distributions. This solution shall be further investigated in future researches.

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Surface Elasticity Effect on the Dynamic Behavior of a Nanowire-Loaded Resonator

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Abstract. This paper presents a transdisciplinary research of an electromechanical quartz crystal resonator (QCR) with consideration of surface elasticity effect of nanowires (NWs) loading arrays, which crosses boundaries of mechanics and electricity, and links macro and nano technologies. The governing equations of NWs are derived from the Timoshenko beam theory in consideration of shear deformation. The electrical admittance is described directly in terms of the physical properties of the surface NWs from an electrically forced vibration analysis. The results will be helpful to the design of nanosized beams loaded acoustic wave sensors and some related applications.

Keywords. Nanowire, quartz crystal resonator (QCR), thickness-shear mode (TSM), electrical admittance, shear deformation, surface elasticity.

Introduction

Nanowires (NWs) have attracted attention in recent years due to their applications in nanomechanical resonator systems [1, 2]. It has been found that the NW elastic modulus is size dependent and may be a result of surface elasticity [3, 4]. This so called surface elasticity effect often plays a significant role in the physical and mechanical properties of micro- and nano-materials and structures [5, 6].

Recently, some researchers have been trying to use a quartz crystal resonator (QCR) in thickness-shear modes (TSM) carrying an array of micro- or nano-beams (see Figure 1) to characterize the geometric/physical properties of these beams from the frequency shift (FS) of this acoustic-wave-based sensor. Liu et al. [7] established a theoretical model of a TSM quartz crystal plate carrying an array of micro-beams (MBs) with their bottoms fixed to the top surface of the plate, in which the beams were modeled by the Euler–Bernoulli theory for beam bending and the bending moment effect at the MBs/QCR interface was not considered. In order to clarify the effect of bending moment on FS, Zhang et al. [8] put a rigid beams/QCR model forward, where couple-stress was introduced into the QCR's governing equations to balance the distributed moments produced by surface MBs at the interface. Kong et al. further performed a series of works based on this two-dimensional model considering the couple-stress [9], and the effect of strain-gradients of surface micro-beams on FS of the compounded system was discussed in detail [10]. These researches focused on the

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influence of the intrinsic characteristics of surface substance-units on QCR FS by free vibration frequency analysis, they ignored the influence of surface elasticity when beam diameter decrease to tens or hundreds of nanometers. In this paper, we use a core-shell composite beam model (common beam with a surface layer of finite thickness) to perform an electrically forced vibration analysis of the resonator admittance to further explore the effects of surface elasticity E_s of beams on the NWs/QCR system properties.

1. Formulation of the problem

1.1. Displacement and stress of an AT-cut QCR in TSM vibrations

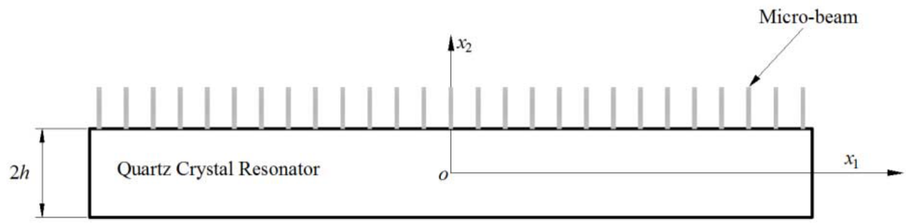

Figure 1. A QCR coated with an array of micro- or nano-beams.

Figure 1 schematically shows an AT-cut quartz crystal resonator covered with an array of circular nanowires (NWs). For thickness-shear vibrations of the QCR, the governing equations are

$$\begin{aligned} &T_{21,2} = \rho_Q \ddot{u}_1, \qquad D_{2,2} = 0, \qquad E_2 = -\phi_{,2}, \\ &T_{21} = c_{66} u_{1,2} + \eta_Q \dot{u}_{1,2} - e_{26} E_2, \qquad D_2 = e_{26} u_{1,2} + \varepsilon_{22} E_2, \end{aligned} \tag{1}$$

where ρ_Q and η_Q stands for the mass density and viscosity of quartz, c_{66}, e_{26} and ε_{22} denote the elastic, piezoelectric and dielectric constants, respectively. Since the crystal plate is under a TSM harmonic vibration, the time-harmonic factor, $e^{j\omega t}$, will be dropped in the following for simplicity, where j is the imaginary unit. Then, we get the general solution for (1) as:

$$\begin{aligned} &u_1 = B_1 \sin k_Q x_2 + B_2 \cos k_Q x_2, \\ &\phi = \left(e_{26} / \varepsilon_{22}\right)\left(B_1 \sin k_Q x_2 + B_2 \cos k_Q x_2\right) + B_3 x_2 + B_4, \\ &T_{21} = c_Q \left(B_1 k_Q \cos k_Q x_2 - B_2 k_Q \sin k_Q x_2\right) + e_{26} B_3, \end{aligned} \tag{2}$$

where B_1, B_2, B_3, B_4 are constants to be determined, and

$$c_Q = c_{66} + e_{26}^2 / \varepsilon_{22} + j\omega\eta_Q, \quad k_Q = \omega\left(\rho_Q / c_Q\right)^{1/2}. \tag{3}$$

1.2. Analysis of NW vibrations with considering of surface stress

When the above QCR is excited into TSM vibrations, the attached NWs in Figure 1 will present flexural motions. Circular NW beam with beam length *L*, beam diameter *D*. Deflection and angular rotation of each beam are denoted as $w(x,t)$ and $\theta(x,t)$ with the bending moment and the shear force as *M* and *T*, respectively.

As seen in Figure 2, the surface beam is modeled with the "core-shell" approach where the surface is assumed as a thin layer. This thin layer has mechanical properties that differ from the bulk material. For a NW, the shear force may become significant to its elastic behavior, it is more suitable to employ the Timoshenko beam theory than the usual Euler-Bernoulli beam theory since shear deformation is taken into account in the former theory.

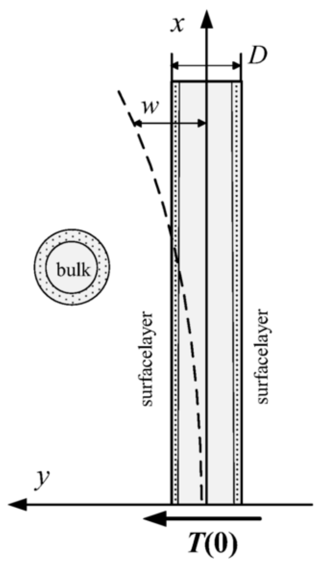

Figure 2. The coordinate system for core-shell composite NW beam bending.

Based on the Timoshenko beam theory [11], we have the following equations of motion

$$\bar{\rho} I \frac{\partial^2 \theta}{\partial t^2} + T - \frac{\partial M}{\partial x} = 0, \tag{4}$$

$$\bar{\rho} A \frac{\partial^2 w}{\partial t^2} + \frac{\partial T}{\partial x} = 0. \tag{5}$$

For the present situation, bending moment *M* and shear force *T*, respectively, take

$$M(x) = (EI)^{*}\theta',\ \ T(x) = \kappa AG(\theta - w'). \tag{6}$$

where E, $\bar{\rho}$, I, A, G and κ denote elastic modulus, mass density, moment of inertia, cross sectional area, shear modulus and shear coefficient of the bulk material respectively. $(EI)^{*} = EI + \pi E_s R^3$ is the effective bending moment [12] of the core-shell sandwich beam.

For harmonic vibration, we can derive the expression of $\theta(x)$ from (4) (5)

$$\theta(x) = \left[\left(\kappa AG + \frac{\bar{\rho}\omega^2 (EI)^{*}}{\kappa G}\right) w' + (EI)^{*} w'''\right] \Big/ \left(\kappa AG - \bar{\rho} I \omega^2\right). \tag{7}$$

According to the above discussion, the following differential equation of vibration for the NW beam in Figure 2 is obtained

$$(EI)^{*}\frac{\partial^4 w}{\partial x^4} - \left(\bar{\rho} I + \frac{\bar{\rho}(EI)^{*}}{\kappa G}\right)\frac{\partial^4 w}{\partial x^2 \partial t^2} + \bar{\rho} A \frac{\partial^2 w}{\partial t^2} + \bar{\rho} I \frac{\bar{\rho}}{\kappa G}\frac{\partial^4 w}{\partial t^4} = 0. \tag{8}$$

Introducing the non-dimensional quantities $\bar{w} = w/R$, $\bar{x} = x/L$ and $\bar{t} = \omega t$. We can write the non-dimensional deflection $\bar{w}(\bar{x}, t) = W(\bar{x}) e^{j\omega t}$ for harmonic vibrations. Then it can be obtained from Eq. (8)

$$\frac{d^4 W}{d\bar{x}^4} + \chi_1 \frac{d^2 W}{d\bar{x}^2} - \chi_2 W = 0, \tag{9}$$

where

$$\chi_1 = \left(\bar{\rho} I + \frac{\bar{\rho}(EI)^{*}}{\kappa G}\right) L^2 \omega^2 / (EI)^{*}, \chi_2 = \left(\bar{\rho} A L^4 \omega^2 - \bar{\rho} I \frac{\bar{\rho}}{\kappa G} L^4 \omega^4\right) / (EI)^{*}. \tag{10}$$

The general solution of Eq. (9) is $W(x) = e^{\lambda x}$, therefore

$$\lambda^4 + \chi_1 \lambda^2 - \chi_2 = 0, \tag{11}$$

The roots of Eq. (11) are $\lambda_{1,2} = \pm i\lambda_\alpha$, $\lambda_{3,4} = \pm \lambda_\beta$, where

$$\lambda_{\alpha;\beta} = \sqrt{\frac{1}{2}\left[\pm \chi_1 + \sqrt{\chi_1^2 + 4\chi_2}\right]}. \tag{12}$$

Thus, we can obtain

$$W(\bar{x}) = C_1 \cos\lambda_\alpha \bar{x} + C_2 \sin\lambda_\alpha \bar{x} + C_3 \cosh\lambda_\beta \bar{x} + C_4 \sinh\lambda_\beta \bar{x}, \tag{13}$$

C_i (i = 1, 2, 3, 4) are unknown parameters to be determined from the prescribed boundary conditions.

The boundary conditions at the tops of MBs are

$$M\big|_{\bar{x}=1} = 0, \quad T\big|_{\bar{x}=1} = 0, \tag{14}$$

and those on the beams/QCR interface are

$$RW\big|_{\bar{x}=0} = -u_1\big|_{x_2=h}, \;\; NT\big|_{\bar{x}=0} = T_{21}\big|_{x_2=h}, \;\; \theta\big|_{\bar{x}=0} = 0. \tag{15}$$

In addition, the bottom edge of QCR is free from any traction. Therefore, we have

$$T_{21}\big|_{x_2=-h} = 0. \tag{16}$$

We stipulate that the potentials on the top and bottom electrode of the quartz are

$$\phi\,|_{x_2=h} = -\phi_0, \quad \phi\,|_{x_2=-h} = \phi_0. \tag{17}$$

Substituting Eqs. (2), (6), (7) and (13) into Eqs. (14) to (17), we obtain the following matrix

$$\begin{pmatrix} bc_Q k_Q & ac_Q k_Q & e_{26} & 0 & 0 & 0 & 0 & 0 \\ ae_{26}/\varepsilon_{22} & be_{26}/\varepsilon_{22} & h & 1 & 0 & 0 & 0 & 0 \\ -ae_{26}/\varepsilon_{22} & be_{26}/\varepsilon_{22} & -h & 1 & 0 & 0 & 0 & 0 \\ a & b & 0 & 0 & F_1 & 0 & F_1 & 0 \\ 0 & 0 & 0 & 0 & 0 & F_2 & 0 & F_3 \\ bc_Q k_Q & -ac_Q k_Q & e_{26} & 0 & 0 & F_4 & 0 & F_5 \\ 0 & 0 & 0 & 0 & F_6 & F_7 & F_8 & F_9 \\ 0 & 0 & 0 & 0 & F_{10} & F_{11} & F_{12} & F_{13} \end{pmatrix} \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ C_1 \\ C_2 \\ C_3 \\ C_4 \end{pmatrix} = \begin{pmatrix} 0 \\ -\phi_0 \\ \phi_0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \tag{18}$$

where

$$H_1 = \kappa AG - \bar{\rho} I \omega^2, \ H_2 = \kappa AG + \frac{\bar{\rho}\omega^2 (EI)^*}{\kappa G}, \quad (19)$$
$$H_3 = H_2 - H_1.$$

$$(a,b) = (\sin\gamma, \cos\gamma), \ \gamma = k_Q h, \ F_1 = R,$$
$$F_2 = -\frac{RK_1}{H_1 L^3}, F_3 = \frac{RK_2}{H_1 L^3},$$
$$F_4 = \frac{\kappa AGNRK_3}{H_1 L^3}, \ F_5 = -\frac{\kappa AGNRK_4}{H_1 L^3},$$
$$F_6 = K_3 \sin\lambda_\alpha, F_7 = -K_3 \cos\lambda_\alpha,$$
$$F_8 = K_4 \sinh\lambda_\beta, F_9 = K_4 \cosh\lambda_\beta, \quad (20)$$
$$F_{10} = K_1 \lambda_\alpha \cos\lambda_\alpha, F_{11} = K_1 \lambda_\alpha \sin\lambda_\alpha,$$
$$F_{12} = K_2 \lambda_\beta \cosh\lambda_\beta, F_{13} = K_2 \lambda_\beta \sinh\lambda_\beta,$$
$$K_1 = \left((EI)^* \lambda_\alpha^2 - H_2 L^2\right)\lambda_\alpha, \quad K_2 = \left((EI)^* \lambda_\beta^2 + H_2 L^2\right)\lambda_\beta,$$
$$K_3 = \left((EI)^* \lambda_\alpha^2 - H_3 L^2\right)\lambda_\alpha, \quad K_4 = \left((EI)^* \lambda_\beta^2 + H_3 L^2\right)\lambda_\beta,$$

In order to determine the admittance, defined as the ratio of current to voltage, an expression for the current must be obtained. Tiersten [13] gives the surface charge over an area *S* for two-dimensional piezoelectric plates as $Q = \int D_2 dS.$ Using Eq. (2) in (1), the displacement is expressed explicitly in terms of B_3 as Accordingly, the charge on the electrode of area S_0 is written $Q = -\varepsilon_{22} B_3 S_0$. The current is the time derivative of *Q*, which means $I = \dot{Q} = -j\omega\varepsilon_{22} B_3 S_0$.

Thus, the admittance of the system is

$$Y = \frac{I}{V} = \frac{j\omega\varepsilon_{22} S_0 B_3}{-2\phi_0}. \quad (21)$$

2. Results and discussion

We consider an AT-cut quartz crystal plate with

$$c_{66} = 29.01\times10^{9}\,\text{N/m}^2,\ \ e_{26} = -0.095\,\text{C/m}^2,$$
$$\varepsilon_{22} = 39.82\times10^{-12}\,\text{C/Vm}, h = 0.0825\times10^{-3}\,\text{m}, \tag{22}$$
$$\rho_Q = 2649.0\,\text{kg/m}^3,\ \ S_0 = 2.047\times10^{-5}\,\text{m}^2.$$

It is readily obtained that the fundamental frequency of uncoated QCR is $f_0 = 10.0355$ MHz. The NWs distribution density N is set as 1×10^{12} units/m^2 in the analysis.

The influence of the surface elasticity on the compound QCR system is examined for silicon nitride NWs with diameter D = 100 nm. The material properties are chosen based on the experimental data of [6] as density $\bar{\rho} = 3100\,\text{kg/m}^3$, Poisson's ratio $\nu = 0.24$, bulk modulus $E = 300$ GPa, surface elasticity $E_s = -1170\,\text{N/m}$.

Figure 3 (a), 4 (a) and 5 (a) present the real admittance spectra of the compound NWs/QCR system versus the normalized frequency f/f_0 without or with consideration of surface elasticity for 3 different NW lengths (L = 1 μm, 5 μm and 10 μm). While Figure 3 (b), 4 (b) and 5 (b) show the corresponding vibration modes of NWs at resonance frequencies of the NWs/QCR system. We further note that the node number of vibration mode in Figure 3 (b), 4 (b) and 5 (b) is 0, 1 and 2, respectively. This indicates that the NWs are under the first-order, second-order and third-order vibration mode accordingly.

Moreover, Figure 3 (b), 4 (b) and 5 (b) together manifest that a negative surface elasticity E_s increase the system inertia [9] by decreasing of the effective stiffness of beams, which is equivalent to the decrease of system nature frequency, thus the admittance spectra moves left in Figure 3 (a), 4 (a) and 5 (a) with consideration of E_s. Further calculation shows that the left FS magnify gradually, alone with the increase of the aspect ratio, from almost zero for aspect ratio L/D = 10 in Figure 3 (a) to 321 Hz for aspect ratio L/D = 50 in Figure 4 (a) and to 1947 Hz for aspect ratio L/D = 100 in Figure 5 (a). The nth mode frequency of a cantilevered beams with surface elasticity can be extracted from [14] as $f_n = \frac{\beta_n^2}{2\pi L^2}\sqrt{\frac{EI}{\rho A}\left(1+\frac{E_s J}{EI}\right)}$, where β_n term is the eigenvalue from the characteristic equation, $\beta_1 = 1.875,\ \beta_2 = 4.694,\ \beta_3 = 7.855,$ correspond to the first three resonance modes for any cantilevered beam. In this research, we keep the diameter of the NW fixed, hence the increase of the aspect ratio is equivalent to the growth in the NW length L, where L = 1 μm, 5μm and 10μm correspond to the first three resonance modes. Thus we can draw the conclusion that the resonance frequency decline proportional to the decrease of β_n^2/L^2, which explains why the left FS enlargeing gradually accompany with the rise of the aspect ratio.

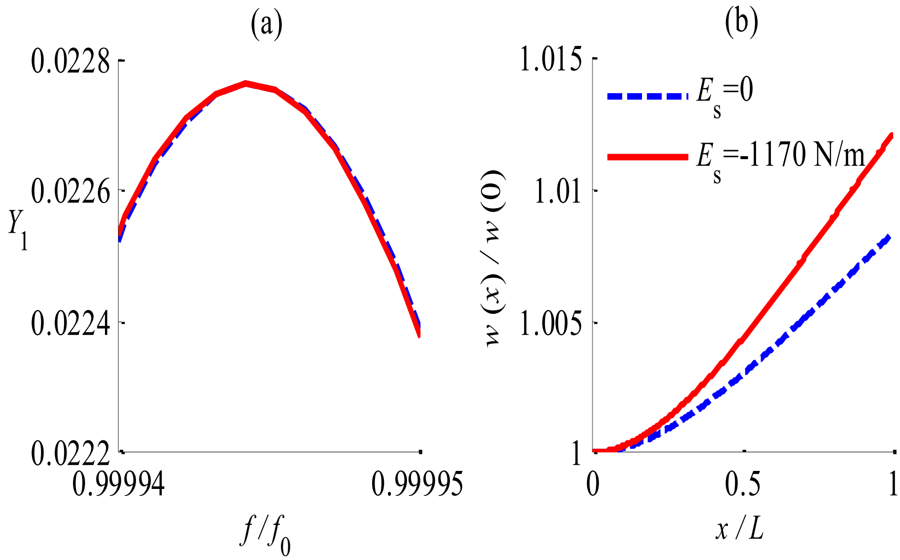

Figure3. (a) Real admittance spectra of the NWs/QCR system with silicon nitride NW length L = 1 μm (b) Vibration modes of NWs at corresponding resonance frequencies.

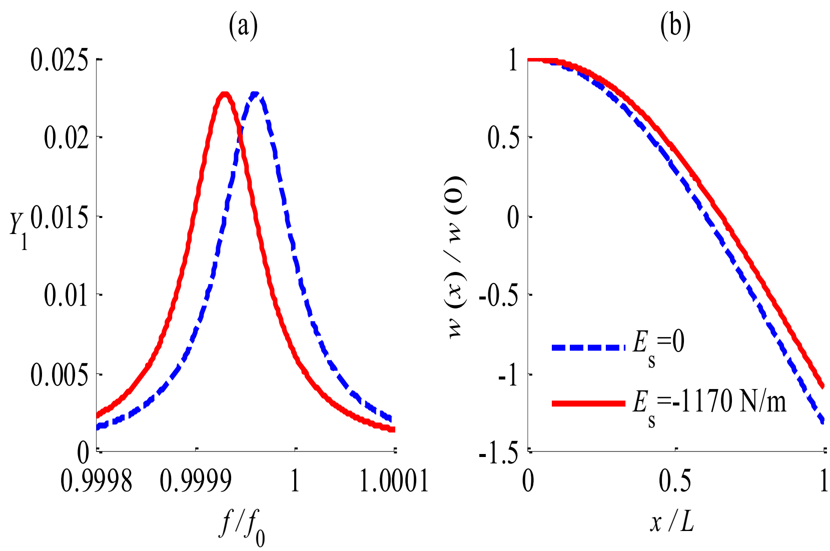

Figure 4. (a) Real admittance spectra of the NWs/QCR system with silicon nitride NW length L = 5 μm (b) Vibration modes of NWs at corresponding resonance frequencies.

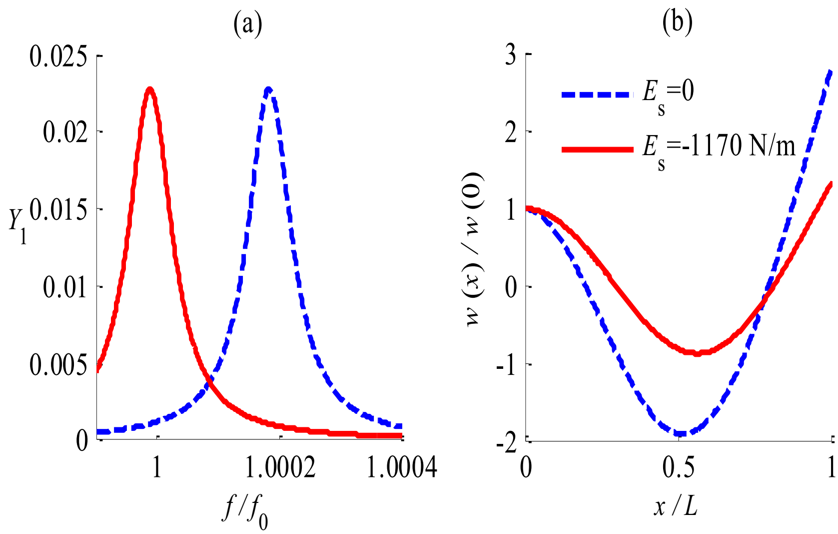

Figure 5. (a) Real admittance spectra of the NWs/QCR system with silicon nitride NW length $L = 10$ μm. (b) Vibration modes of NWs at corresponding resonance frequencies.

3. Conclusions

The influence of the surface elasticity on the electric admittance and vibration modes is examined for silicon nitride NWs/QCR compound system. It is found that a negative surface elasticity increase the system inertia and decrease the system nature frequency, and the left FS induced by this negative surface elasticity also increases gradually alone with the increase of the aspect ratio. The FS is very small when the aspect ratio L/D is small, while the surface elasticity makes a greater contribution to the FS when the aspect ratio L/D becomes larger.

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Part 16

Knowledge-Based Engineering

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A Framework for Capturing and Applying Design Knowledge in Complex Systems

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Abstract. The large amount of available design information from different areas has become common in most organizations. Under these conditions, there are difficulties in sharing and reusing knowledge, especially by the fact that this knowledge is available within the company in different formats and locations. Due to this, design engineers often fail to use such information. To ensure a better use, it is important to organize and integrate the available knowledge in a collaborative manner. In this context, the Knowledge-based Engineering (KBE) approach can be associated. Through KBE concepts, the current study aims to develop a set of tools for assisting decision making, by storing and providing useful information in a timely manner. Such solution should meet the needs of its users (i.e. designers), as well as improve the quality of design activities along the Product Development Process (PDP). For this study, still under development, the following steps have been adopted: (a) delimitation of action scope (i.e. steps of PDP to be focused); (b) knowledge capture; (c) knowledge structuring through ontologies; (d) standardization; (e) development of rules; (f) creation of application solutions; and (g) performance evaluation of solutions. The application of the present proposal is expected to facilitate the access to information, significantly reduce the number of Engineering Change Requests (ECR's), as well as allow acquired knowledge to be used in subsequent projects (e.g. lessons learned).

Keywords. KBE, Knowledge Capture, Ontology, PDP.

Introduction

It is a common practice, not only in the automotive industry, but also in other segments, that good design practices of complex systems are available in the form of standards or other records of technical expertise. At various locations and formats, these are not always applied by project teams. Due to difficulty of access, time restrictions or the way information is made available, many products flaws (i.e. non-conformities) end up occurring due to valuable analyses that are skipped or information that cease to be supplied to subsequent project activities. These issues were confirmed during an evaluation of the development process of a company, which was the basis for the present study.

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Neglecting information at the beginning of the product development process (PDP) and the subsequent appearance of flaws causes increasing rework, which, in turn, makes design development longer.

In this context, the present research for technologies and methodologies for capturing and reusing knowledge, also referred as Knowledge Based Engineering (KBE), has been considered. Therefore, the focus of the present research is to develop a solution, in the form of an expert system based on an ontology model, that meets the needs of its users (i.e. designers), as well as improves the quality of design activities along the Product Development Process (PDP). Based on a diagnosis a group of critical components was set, i.e. hydraulic hoses, which will serve as the basis for the study.

To this end, some steps have been adopted: (a) delimitation of action scope (i.e. steps of the PDP to be focused); (b) knowledge capture; (c) knowledge structuring through ontologies; (d) normalization; (e) development of rules; (f) creation of application solutions; and (g) performance evaluation of solutions.

This article is structured as follows: Section 1 presents some of the important concepts for this study and related studies, Section 2 presents methodological aspects, Section 3 shows part of the activities necessary for the development of the solution, Section 4, discussion and Section 5, final considerations.

1. Theoretical Background

Faced with the problem previously elicited, most organizations have been concerned with the availability and management of knowledge. The main reasons for this increasing concern are given by globalization of business, need to quickly develop products, frequent changes in organizations and increasing technological advancements [1]. In this scenario, it is important to introduce some concepts to develop the solution proposed in this study. Among them are the flow of information in the PDP, KBE, knowledge capture, ontologies and expert systems, which are presented as follows.

Along the PDP, there are several flows of information that involve different areas. According to the PDP proposed by [2], much of this information accumulates in embodiment and detailed design phases [10]. In addition, Product Life-cycle Management (PLM) tools are not able to manipulate all the information involved. Thus, it is necessary to conceptualize the knowledge that should be generated and applied in each phase of the PDP [3]. Figure 1 presents a representation of the information flow with some examples of associated knowledge (i.e. needed or developed) at every step of the PDP.

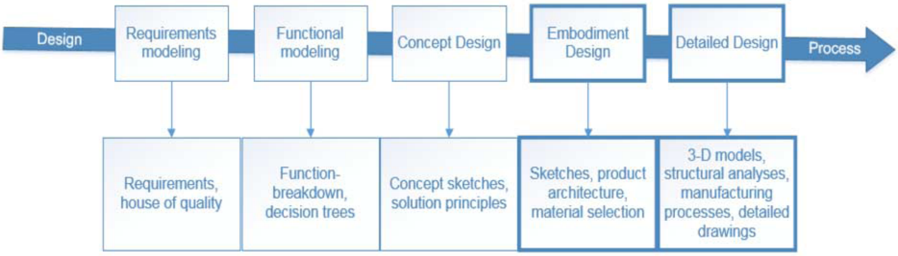

Figure 1. PDP steps associated with types of knowledge representation

Source: adapted from [10]

Given this large amount of information and the need to develop resources to assist organizations for sharing this knowledge, the investigation of KBE approaches is fully justifiable.

KBE can be characterized as a set of solutions capable of assisting the development of engineering activities in different steps of the product development process, in the form of knowledge-based systems. According to the definitions proposed by [3] and [4] it is possible to highlight the ability of KBE on providing development solutions that enable the automation and customization of design activities, by the union of object-oriented programming (OOP), artificial intelligence (AI) techniques and CAD technologies. Moreover, object-oriented KBE systems technologies allow the construction of object classes that contain several useful representations related to the product (e.g. geometry definitions, costs) [5], which make knowledge explicit. Another characteristic of KBE, more recently suggested, is the ability to create frameworks to capture, store and reuse the knowledge acquired [4].

In this sense, KBE solutions can contribute both with traceability, reuse and search for knowledge, which ensures a collaborative environment and the possibility of reduction in design time, by the automation aspect associated. However, to develop a KBE application, one of the first challenges is the elicitation of knowledge [6].

There are several ways presented in the literature that assist in the elicitation of knowledge. According to [7], it is possible to categorize the capture or elicitation of knowledge in direct and indirect methods. Direct methods (e.g. interviews, case studies, simulation) involve direct questioning the experts of a particular domain on how their activities are carried out. Indirect methods (e.g. role-playing, document analysis, laddering) are those used when information is difficult to express. Another study [8] points out that, among the most appropriate ways to capture tacit and explicit knowledge (both groups and individuals) are questionnaires, interviews, storytelling, brainstorming and round-table method. The purpose of questionnaires and interviews can be related to explicit knowledge, i.e. previously verbalized/formalized. Other mentioned ways make it possible to capture tacit knowledge, that is, knowledge a given expert has acquired over time. The acquired knowledge should be structured to enable subsequent reuse and traceability.

Among various ways of representing and structuring knowledge, one is the use of ontologies. A literature review indicates the use of ontologies for structuring knowledge, as pointed out by [9], [10], [11], [12] and [13], stands out. According to [14], ontologies are an explicit specification of conceptualization and any knowledge base or knowledge-based system is linked with some conceptualization, implicitly or explicitly. Also, [15] refers to ontology as a special type of object information or computational artifact. Computational ontologies are a way to formally model the structure of a system (entities and relationships that emerge from these observations) and which can be used for a specific purpose.

A formal language is needed to build an ontology. Based on RDF (Resource Description Framework), OWL (Web Ontology Language) has a well-defined syntax, which is a basic condition to allow machine-processing [15]. The purpose of this language is to meet two main requirements: support effective reasoning and provide a more complete logical expression. However, these two requirements are contradictory, which led to a subdivision of the language in OWL Full, OWL DL and OWL Lite [15]. Among them, OWL DL (short for Description Logic) would be the intermediate language to meet these two requirements; it restricts some constructions while ensuring greater efficiency in terms of reasoning support.

The study presented by [16] highlights the main benefits of ontologies: the principle of sharing by the semantic expressiveness of ontologies, possibility of creating complex models and the possibility of increasing the community share for providing a wide range of applications. In addition, [16] emphasize that a resulting conceptual model must be transformed into an executable scheme before it can be implemented and applied in a system.

One way to implement ontological models is through expert systems. Expert systems are AI applications whose goal is to represent the knowledge of an expert and thus help in decision-making activities. Generally associated with knowledge-based systems (KBS), AI allows both computers and humans to understand the knowledge expressed through them [17] and their problem solving capability makes the realization of useful inferences for its users possible [18]. By creating rules, it is feasible to evaluate the data contained in a domain to achieve a particular goal [19].

Given these fundamental concepts and the issue raised in the introduction, some studies found in the literature, related to the study, are presented as follows.

There are solutions associated with CAD tools that enable the insertion of knowledge for design automation and other applications. In the studies presented by [20] and [21], commercial CAD systems are used to drive design activities in order to automate the geometric definition of products. [22] presents a solution to convert information from geometric and simulations models (i.e. CAD, CAE) into a centralized and structured knowledge model through a tool, which ensures knowledge acquisition and consistency of parameters and constraints. These proposals, however, do not meet the need to use other forms of knowledge other than those from geometry and simulations, which are also important to the design.

In other studies, the use of formal ontologies to represent knowledge from design activities are proposed. [9] and [10] point the use of formal ontologies to represent assembly information mainly for knowledge sharing, by establishing concept semantics in this domain. [11] use a formal ontology to represent knowledge in the form of standards which, associated to computational meaning, brings greater expectations for more meaningful use of such information. The study conducted by [23] presents a method to capture potential relationships in a large set of data through the use of an ontology, which allows storage and reuse of knowledge. A graphical tool provides a user-friendly interface and the method based on ontologies described in the article helps the integration of heterogeneous data sources.

However, it has been observed that none of these works presents a friendly solution to the user, able to cover the various knowledge sources and formats (e.g. manufacturing requirements, standards, good engineering practices) necessary for designing components and subsystems. Therefore, the solution proposed in this paper is a suitable answer to this research opportunity. Its methodological aspects used are presented next.

2. Methodological aspects

The present research work was carried out with reference to the approach called DSR (Design Science Research) [24]. This approach has been developed facing the need to differentiate studies related to the natural sciences from those related to project science. In the first case, the studies are related to how and why things happen. In the latter, they are related to how things should be to meet certain objective. Thus, DSR's main function is the development and design of artifacts, that is, means by which it is possible to achieve a goal.

In this sense, this work presents an ontological model as the artifact to be designed. Models represent situations as problem and solution, to describe tasks, situations, or, in this case, artifacts.

The DSR approach provides a set of work phases, which lead to the proposal of a consolidated and approved model for use. They are: (i) Problem Identification and Motivation; (ii) Definition of Goals and Solution; (iii) Design and Development; (iv) Demonstration; and (v) Evaluation. Each of these steps is detailed as follows. The present research work is currently in the Design and Development phase.

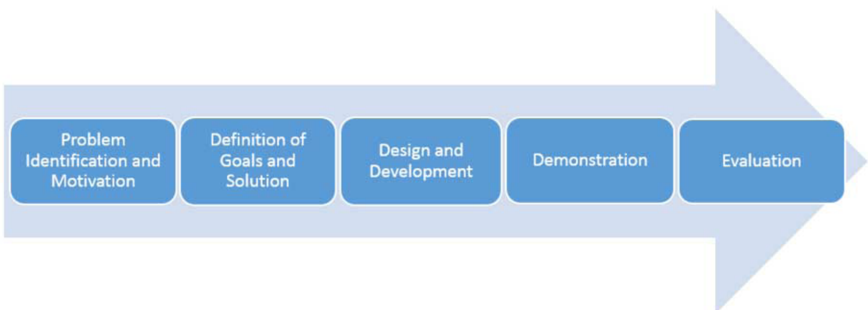

Figure 2. Methodological structure framework based on DSR approach

According this approach, the creation of an ontological model happens through a sequence of steps and activities in each phase. In step 'Problem Identification and Motivation' a strategy based on the analysis of Engineering Change Orders (ECOs) was adopted. For this analysis, a product was initially set as a reference, chosen for it provided a large number of change requests associated. Then all ECOs related to this product have been raised. A classification was subsequently carried out in order to identify and organize the number of ECOs with respect to the product systems and components, resulting in a list. After that, an assessment based on all listed components enabled the definition of which were the most critical ones. Consequently, among the most critical components, it was possible to highlight flexible elements (i.e. hydraulic hoses and electrical harnesses). Careful analysis of the information submitted by design engineers related to the development of their activities revealed that many of the ECOs resulted from neglecting or inappropriate use of design information during the detailed design phase.

In step 'Definition of Goals and Solution', it was decided that the designers could benefit from this work through an expert system based on ontological models, which could contain the knowledge necessary for the design of flexible elements such as hydraulic hoses and electrical harnesses. Currently, designers are pressured to quickly develop projects directly in CAD tools, so that they often fail for not implementing many important aspects related to good design practices. Such information is usually available in standards and recommendations, or even tacitly, from the experience gained in past projects. An expert system could work not only as a repository of this knowledge, but also as driver element for proper work of designers. Ontological models, in turn, allow the knowledge of a particular domain to be registered, debugged and propagated for future use.

For the 'Design and Development' of the artifact, the following activities were carried out: (a) specification; (b) conceptualization; (c) formalization and; (d) implementation [25]. Specification corresponds to identifying relevant information of a specific situation (i.e. domain). Conceptualization is characterized by the development of a conceptual model of the ontology to be built. In Formalization, the conceptual model content is described more formally, i.e. through the assignment of properties and axioms. Implementation is the step in which the ontology, through a knowledge representation language, becomes a formal model and allows querying and inferencing.

During Specification, the artifact application domain has been set, that is, design of hydraulic hoses. Then in Conceptualization, the main classes of the ontology were determined. For that purpose, mind maps were used. In Formalization, the classes that were previously discovered were organized in the form of a taxonomy. In this phase, Protégé ontology editor was used. Finally, in Implementation, axioms that express the key concepts of the model were built, as well as the object properties, datatype properties and individuals.

For the Demonstration phase, a user-friendly interface is to be presented, in which searches for information related to the design domain of hydraulic hoses can be performed. Thus, design engineers can access more easily and quickly information needed to develop such components. For the Evaluation stage, the intention is to use this interface in the corporate environment, to verify that the proposal actually meets the needs of designers, or whether adjustments or implementations need to be made. According to the DSR methodology to evaluate the artifact proposed in this work certain criteria are required. Such criteria correspond to the fidelity of the model with respect to reality, completeness, robustness, consistency and level of detail.

3. Proposed Solution

Following the sequence of activities presented on the methodological aspects to build the artifact, i.e. the ontology model, initially captured knowledge has been structured in the form of mental maps. Figure 3 shows part of an internal standard of the company in the form of mind maps as an example. This standard specifies class types of hydraulic hoses, each of which is associated with classes from SAE J517 and J30 standards.

Furthermore, technical features of each type of hose are defined, as dimensions, materials, work temperature and pressure, among others.

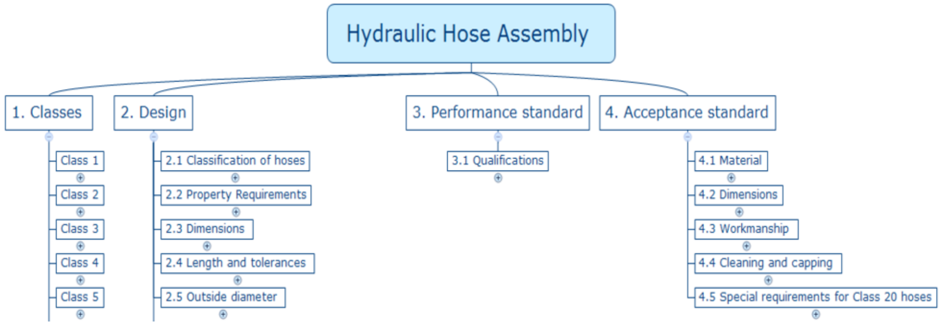

Figure 3. Representation of one of the standards in the form of mind maps

Next, the taxonomy of the ontology model was defined. For the construction of this taxonomy, the following key classes were created: HoseOptions, TechnicalFeatures and SupplierOptions. The representation of this taxonomy with the main classes and its subclasses is illustrated in Figure 4, through the Protégé ontology editor. The TechnicalFeatures class and its subclasses (e.g. ES-B120, TemperatureRange, Atribute, SAE, LengthGroups, Material and PressureRange) are presented in figure 5, in Protégé´s OWLViz plug-in format. It is important to emphasize that the class hierarchy has changed and readapted several times throughout its development to improve the domain representation.

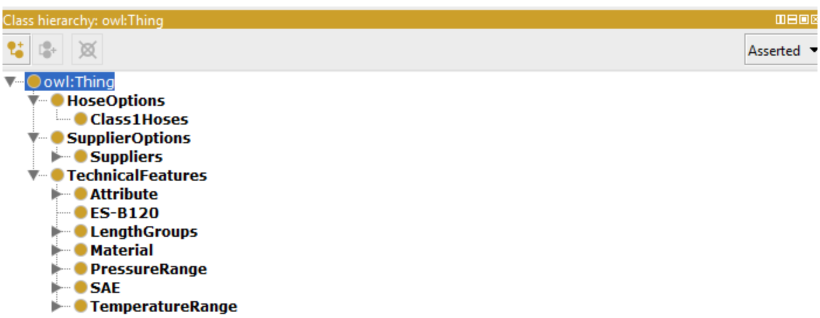

Figure 4. Protégé screen of class hierarchy of the proposed model

In order to correlate the classes, axioms and object properties were created. In addition, datatype properties were created to relate objects to values of data types. As illustrated in Figure 6, it was possible to describe one of these subclasses using object and datatypes properties. In this case, subclass named Class1 is described according to the material, diameter and pressure. Through properties, these features describe what characteristics a hose must present to belong to that class.

To verify possible inconsistencies in the model, one of the Protégé´s reasoners, called Pellet, was used. A reasoner checks if there is any contradiction in the ontology, comparing tested classes with the resulting knowledge base [26]. The results of this check indicated that none inconsistency was found in the proposed model.

Figure 5. Protégé OWLViz plug-in screen with TechnicalFeatures class and its subclasses

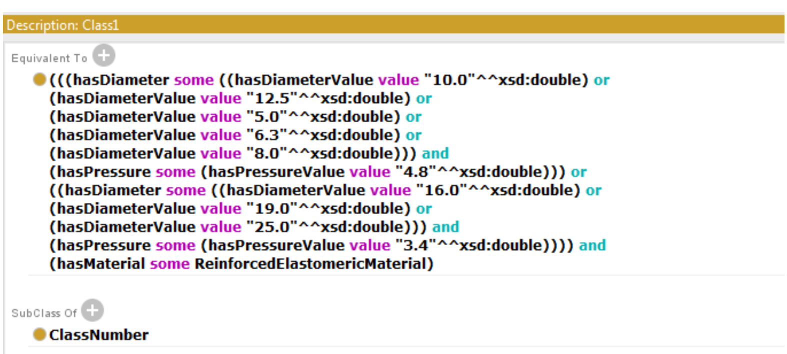

Figure 6. Protégé screen of class description of the proposed model

The ontology model presented in this work should be further implemented. By adding new classes, properties and individuals, the aim is to make it more representative with respect to the proposed domain.

4. Discussion

The research conducted throughout this study showed that there are still many difficulties regarding the issues involving the knowledge generated in organizations. Even with technological advances and availability of new tools, companies encounter problems caused by the unavailability or non-use of design information.

Faced with the activities so far carried out to develop the solution proposed in the study, the structure of the ontology model was the most challenging. The model has been amended several times to represent more adequately the knowledge domain without generating inconsistencies.

As sequence of this study, it is initially intended to increase the ontological model to make it more representative. To do this, information related to manufacturing, costs and lessons learned from previous projects should be introduced. Furthermore, the use of queries in the ontology should be performed to identify individuals created, that is, to obtain inferred information from the domain.

The next step is to develop a user-friendly interface that can be easily used by designers. Through this interface, the user should be capable to access the knowledge represented in the ontology using pre-determined rules. To this end, this study must go through the steps of standardization and creation of those rules.

Some pros and cons of using the solution may already be predicted. On the one hand, the solution can improve the performance of activities associated with hydraulic hose project and allow greater reliability of the final product, i.e. lesser susceptibility to failures. On the other hand, such a solution requires a specialized ontology engineering team to perform the updates that are required over time, such as the introduction of a new supplier or a revision of standards.

5. Final considerations

To meet the demand for provision of knowledge during the detailed design stage, an ontology model was presented. This model ensures the structuring of knowledge in a given domain, here defined as the project context of hydraulic hoses. The knowledge associated with this domain was captured and structured through building the fundamental taxonomy proposed. In addition, object and datatype properties have been created to relate classes with other entities.

This study shows the potential union between ontology models and expert systems to achieve a system that actually is able to meet the needs of design engineers. From this association, it is possible to develop a solution capable of creating a collaborative environment, which contains knowledge from different areas and in different formats.

Such solution should allow the availability and faster use of the knowledge acquired, bringing benefits such as the reuse of knowledge in future projects and the reduction of engineering change requests.

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Generative Modeling in Ultra-Efficient Vehicle Design

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Abstract. Fast and dynamic development of engineering and technology forces designers to reduce time which is needed to design new technical object. The result of this process was fast development of Computer Aided Design (CAD) methods and with the development of such systems new knowledge focused on design methods based on Knowledge-based Engineering (KBE) were developed. One of KBE approaches connected with the application of CAD systems is Generative Modeling, which automates routine design performed in CAD systems. As a result design features, whole parts and even whole assemblies can be generated automatically in CAD system. These generated assemblies and elements can adapt to changed input data. Thus, Generative Modeling method can increase the speed and quality of designed elements. As a use case for application of generative modeling subassemblies of ultra-efficient electric vehicle and drive transmission assembly were used. The process of constructing generative models of assemblies and systems of ultra-efficient car was described, especially acquisition of knowledge and creating knowledge model up to integration knowledge with CAD system - in this case it is CATIA V5. The problems faced during the process of processing knowledge and solutions to these problems were addressed. Additionally, further steps for development of the models and the advantages of generative modeling approach were described.

Keywords. Knowledge-based Engineering, Generative Model, Ultra-efficient vehicle, CATIA V5, MOKA Methodology

Introduction

Development of Computer Aided Design (CAD) systems reduces time needed to design and made new technical object. Thanks to that, designers have extra time to work on new and creative methods of designing [1][2][3]. The development of new methods and techniques which allow to automate some of routine design tasks results from this phenomenon. In the 80s of the last century works began, which resulted in the use of knowledge to automate some routine design task. To allow this, knowledge bases started to be created, which might be used in CAD systems[2][4][5][6][7][8]. In the process of design, knowledge is very important because the whole process based on knowledge, develops this knowledge and creates new. In order to implement knowledge into CAD systems it was needed to create new tools or develop the existing

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ones. The effect of this work was dynamic development of KBS (Knowledge Based System) and KBE (Knowledge Based Engineering) [2][5][7][9]. As part of this work many methodologies were created which allow to acquire and save knowledge in an appropriate form. But using this methodologies directly in CAD software was insufficient. Thanks to the appearance of modulus like Knowledgeware it was possible to create Generative and Integrated models [1][3][5][9][10]. They combined together the aspects of design and knowledge engineering which could allow to create model which can automatically generate feature of a part, whole parts and even the whole assembly. Such type of model can generate alone not only geometry of element or assembly but also make verification of strength or check if generated element is feasible and if it is necessary to make some corrections [1][3][7][11]. This paper focuses on the procedure of Generative Models preparation, in particular on aspects associated with creation of the model in CAD software - in this case it was CATIA V5.

With shrinking resources of fossil fuels there has been a fast and dynamic development of electric drive systems. Because the amount of energy which can be stored on vehicle developing high efficient subassemblies is one of most important task for designers. The best areas for introduction and development of such type of solutions are challenges like Shell Eco-marathon where innovative solution for ultra-efficient vehicles are developed and which in turn allow efficient management of energy and the increase of traveled distance on one charged. The Smart Power team of students and scientists has participated in these races since 2012 successfully by building electric vehicles in *battery electric* and *hydrogen fuel cell stack* energy source category and *Prototype* or *Urban Concept* type of race car. The team is placed in the top ten best teams. The team also holds the record for Poland in three racing categories in the construction of energy-efficient vehicles and energy-efficient driving [12][13][14]. There is a need for constant changes in prototypes and optimization of technical solutions ready for a quick change of design and adaptation to changing conditions. Application of Generative Modeling is the best answer to these challenges.

1. Process of preparation of Generative Model

The process of generative model preparation can be divided in two basic stages: preparation of knowledge model and preparation of CAD files. First stage is usually the hardest part because it requires knowledge on the field of knowledge engineering. However, preparation of CAD files can be different depending on the used CAD system. In this paper CATIA V5 is used and all operations are adapted to the requirements of this software. The process of preparation of knowledge model is very well known and described in many of methodologies. But the process of preparation of model in CAD is dependent on used system, so that is why it is difficult to find any schematic or algorithm how to make Generative Model. In this part of paper we want to show what this process looks like in CATIA system and why we focus more on aspects related to CAD software.

1.1. Process of knowledge acquisition

For the correct operation of generative model appropriate knowledge associated with the designed object is needed [6]. In case of design knowledge, the knowledge is defined as information combined with context, reflection, experience which is necessary in design process [12]. While designing many type of sources of knowledge are used e.g. guides, books, professional literature, previous projects, competitive solution, norms, etc. The main source of knowledge is knowledge from experts-designers, who have practical experience and can interpret other sources of knowledge [6][11]. In order to acquire knowledge from expert many special techniques which reduce time and increase efficience of this process were developed. One of the most popular techniques is the technique of preparation of protocols [6][16][17]. Protocol is understood as any record (paper document, audio or video record) created during the conversation with an expert. Such conversation usually is a kind of interview during which an expert answers questions from a knowledge engineer. During this interview a lot of information is acquired which needs some extra work to make it useful in the next stages [6][16][17]. Figure 1 presents further stages of knowledge acquisition process. The process of knowledge acquisition usually requires cooperation with experts? or experts elaboration. Knowledge engineers have hard work because most of experts do not want to share their knowledge and experience which they have obtained for many years of work [6][7][11]. Many experts see a threat in this new technique of design because they are afraid to be replaced by intelligence models. This approach is incorrect because such type of model may help in routine design task and give extra time to work on more creative and innovative parts of project. Another problem is the approach of design offices. In many of offices nobody collects information about actions taken in the course of work on the project which makes work of knowledge engineer difficult [6][7][11].

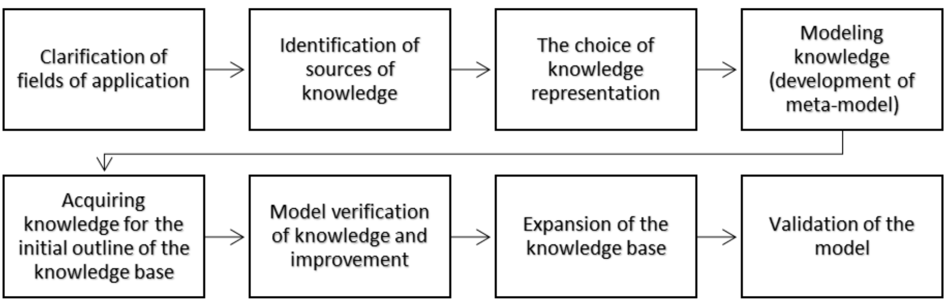

Figure 1. Further stages of knowledge acquisition process.

Even if a knowledge engineer acquires the required knowledge, he/she will have to choose method of formalization and save it in correct form of this knowledge. To aid work related with preparation of knowledge model, special software such as PCPACK or Protégé is used [16][17][18]. Regarding the choice of methodology and thus the choice of meta-model there are many predefined methodologies of recording knowledge in clear and easy to read form, such as MOKA or CommonKADS [5][9]. One of most popular methodology used in building KBE (Knowledge-based Engineering) systems is MOKA (Methodology and tools Oriented to Knowledge-Based Engineering Applications) [9][11][19]. This methodology assumes creation of two types of knowledge models - formal and informal. Informal model has to be easy and friendly in use for a user who is not an expert in the field of computer techniques. Whereas formal model is used to save knowledge in a form which can be directly used in KBS (Knowledge-based System) or CAD/CAM (Computer Aided Manufacturing) systems [9][19]. Figure 2 presents a form of MOKA informal model prepared in Protégé system [4][9][18][19].

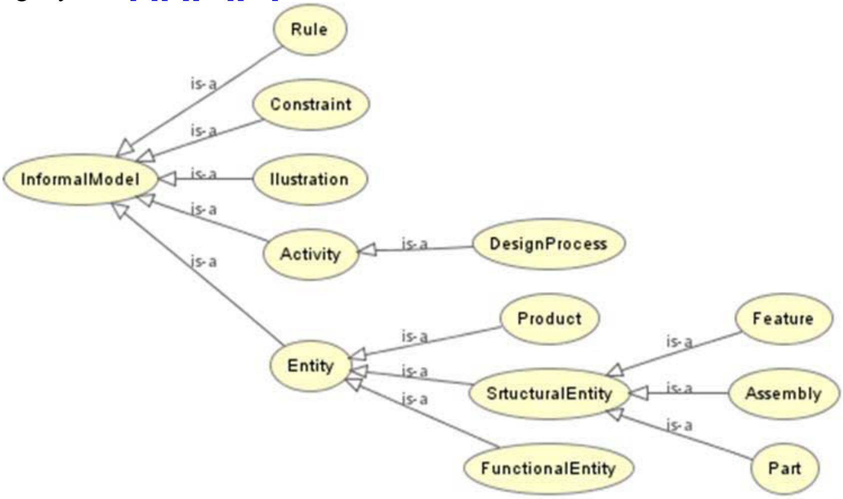

Figure 2. Informal model according MOKA methodology.

The choice of proper methodology and system to aid knowledge acquisition, automatically imposes certain issues related with multi-layer model of knowledge, such as a form of meta-model, language used to save knowledge, etc [6][7].

1.2. Preparation of Generative Model CAD file

Figure 3 shows a cycle of preparation and development of Generative Model CAD files.

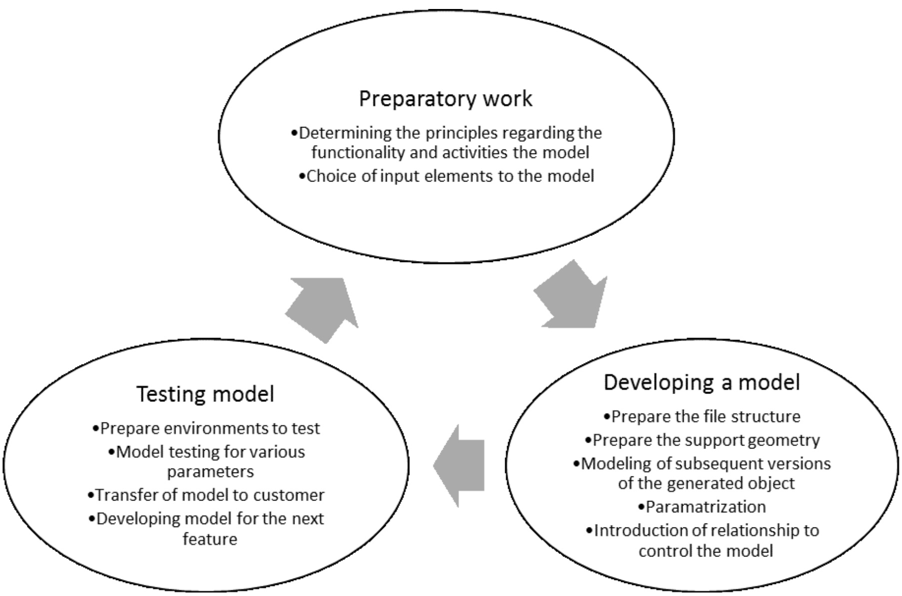

Figure 3. Generative Model creation procedure.

1.2.1. Preparatory work

To allow proper work of Generative Model a designer should consider how a prepared model should work and in what form it should be saved. In CATIA V5 there are three types of Generative Model: PC (Power Copy) and UDF (User Defined Feature) to generate features of part and DT (Document Template) for parts and assemblies. Regarding the assumptions concerning the actions of model it is important to rethink which parts of generating process should be done automatically and which by a user. In contrast to parametric model, Generative Model generates object based on inputs elements and not only value of parameters. As inputs elements of the model we understand any geometrical elements or parameters which can be used to generate object. Selection of input elements is very important because it has big influence on support geometry and geometry of generating object. Common rule is that to choose as input elements in accordance with the design practice as design or technological supports for example to generate bearing natural inputs are cylindrical surface of shaft and axial support surface. The value of force, durability, etc. can be chosen as input parameters. Minimization of input number favors ease of interpretation and application.

1.2.2. Preparation of file structure

In order to facilitate the work with model preparation of proper structure of file should be a habit. This approach makes file more readable and clear. Example structure of file for Generative Model was presented in Figure 4.

Figure 4. Structure of Generative Model file.

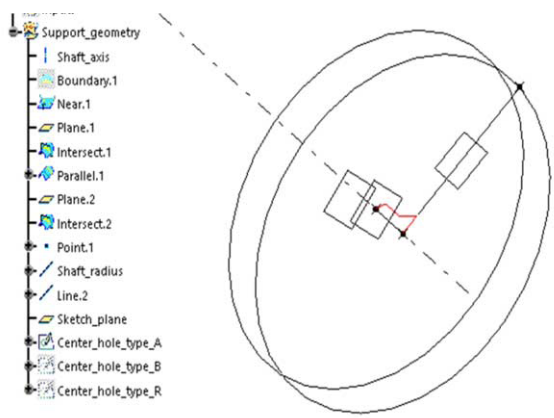

Figure 5. Example elements of support geometry.

Within the structure of Generative File it is possible to extract some functional groups. For example Support Geometry group contains every elements related to support geometry and in next PartBody (Realization_1F, 6F, etc.) next versions of generated geometry of object are saved.

1.2.3. Preparation of support geometry

Support geometry is created based on input elements. Any type of lines, axis, plane, points, etc. which are necessary to correct orientation model in space are included in support geometry. Model should be oriented in space in a way to be independent of global coordinate system and should be used to orientation of construction and technological base. Figure 5 presents an example of elements of support geometry.

1.2.4. Development of next versions of generated object

Another step in the development of Generative Model is modeling next versions of generated object. Usually at initial stage of work the frequently used solution of generated object are developed and in next phase of development the model is completed with next solutions. In such type of model every sketches and dimension should be parameterized by appropriate parameters and relationship. Only fully parameterized object can be used in process of generation, additionally appropriate rules and checks should be included which are responsible for choosing correct version of object, parameter value, etc. So prepared model saved in appropriate form can be called Generative Model which is able to facilitate the task and increase speed of routine design task in designing new technical objects.

1.2.5. Model testing

Last stage in the preparation of Generative Model is process of testing. To do this it is necessary to prepare environment for testing. Testing environment should give as many use cases of model as it is possible. After testing phase model is transferred to customer. It happens quite often that after preparation of final file another amendments are introduced to expand functionality. In order to do this it is necessary to apply the entire procedure described above. In next part of this paper the process of preparation of Generative Model for synchronous belt transmission will be described.

2. Use case: Generative Model for ultra-efficient electric vehicle subsystems

During the process of designing of ultra-efficient electric vehicle construction is optimized to reduce energy consumption. Multi stages process of optimization forces necessity of fast changing of designing construction. To meet these requirements in process of designing many of subassemblies Generative Models are used. One of the examples which used such type of model is drive system assembly of synchronous belt transmission with toothed belt.

2.1. Design of knowledge model

In belt transmission case almost all knowledge can be acquired from experts elaborations such as books, norms and guides. Thanks to this in the process of development of knowledge model it was not necessary to cooperate with expert and this in turn made process of knowledge acquisition easier. To prepare knowledge model it is necessary to choose tools which will be used to acquire required knowledge. In this case it will be free software Protégé, so that choosing this tool automatically determines OWL language as the language which will be used. Using Protégé and information acquired from books and norms, knowledge model based on MOKA methodology was created. Part of informal knowledge model was presented in Figure 6.

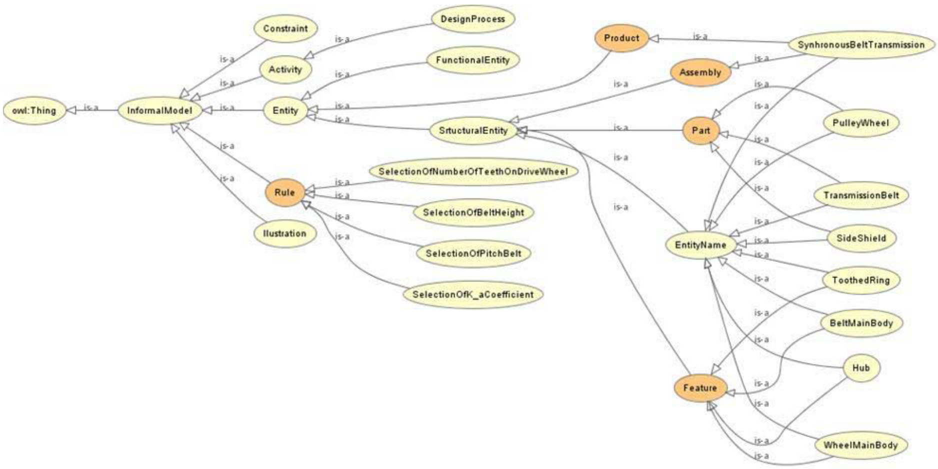

Figure 6. Informal knowledge model for belt transmission.

2.2. Preparation of Generative Model file

Based on acquired knowledge it was decided that input model elements will be cylindrical surfaces of shafts (driven and drive) and planes to align wheel on shaft. As input parameters power of engine, rotation speed of engine, gear ratio and coefficient of overload which were saved in main assembly have been chosen. Geometric inputs represent construction base and parameter inputs represent functional assumption. Because generated object is an assembly the structure of Generative Model file is a little different than this presented in Figure 4. The structure of belt transmission Generative Model file is presented in Figure 7.

Based on prepared file structure subsequent versions of belt wheels were gradually introduced. Using knowledge acquired in the process of Generative Model creation a model which can automatically adapt to changing design environmental was created (Figure 8). Three different versions of belt wheel are presented in Figure 9, all of these wheels were saved in special PartBody. The same steps must be followed in transmission belt case.

All the created models are fully parameterized and values of individual parameters are controlled by appropriate relationships and checks. Last steps of work with Generative Model is testing. To do this special test environment was prepared consisting of two shafts and few parameters. Test environment and effect of using prepared Generative Model are presented in Figure 10.

The described model is one of many which were developed. Other generated elements include clutch, bearing, elements of steering system and suspension. By using such type of model the time needed to make change in the design was reduced and it enabled us to focus on more important task. Prototype version of drive system was made and used in ultra-efficient vehicle which is protected by the patent.

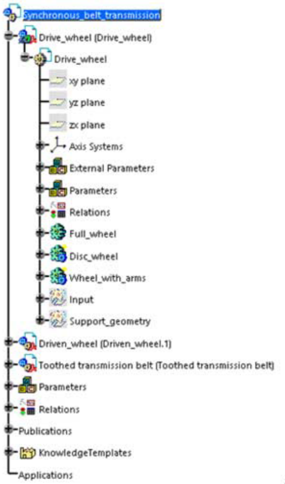

Figure 7 File structure for belt transmission.

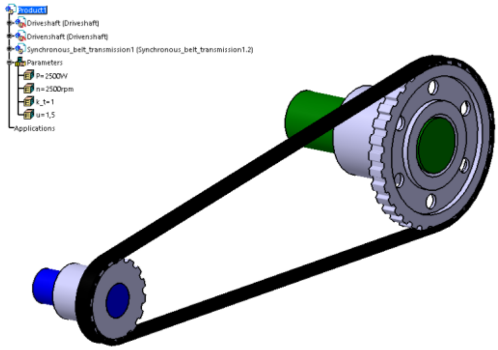

Figure 8 Effect of using Generative Model.

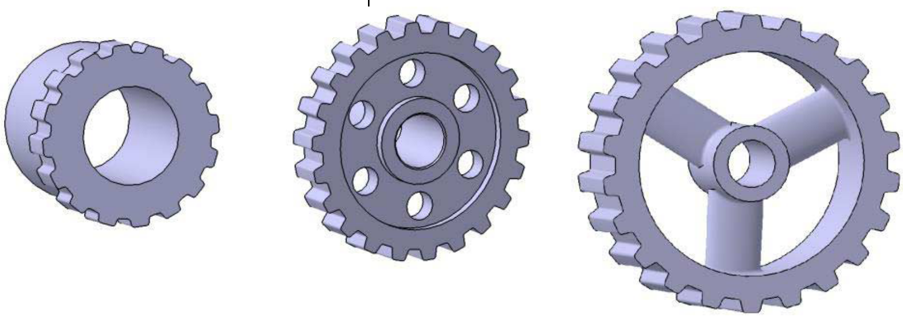

Figure 9 Three versions of belt wheel.

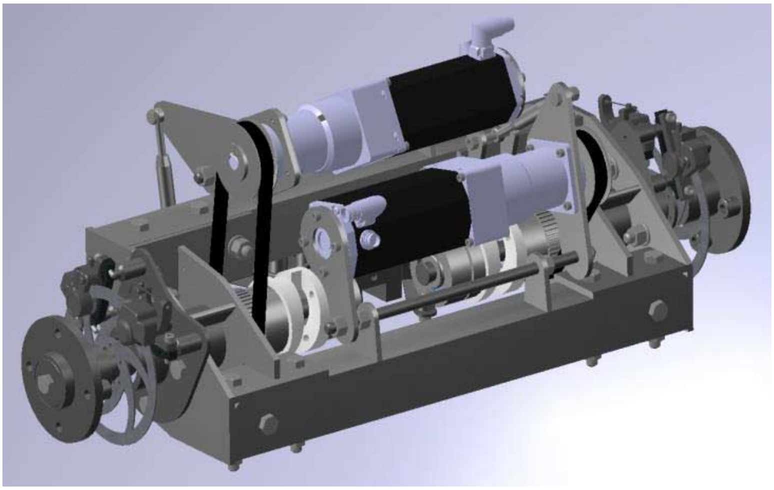

Figure 10 Prototype version of energy-efficient drive transmission model [14].

3. Conclusions

Using one of new design methods such as Generative Modeling allows to make fast changes in a project which is very important in designing and optimization process. Possibility of automatical adaptation of some elements to others increases the speed of redesign process and makes it easier, because designers do not need to search for information about designing object or make long and hard calculations. All these things are done automatically by Generative Model, taking into account other elements which provide associativity of design elements. Generative model needs continuous development to make it better and expand area of application. Therefore, designers should not be afraid of changes but see the benefits of such an approach and learn how to use it. This type of modeling changes the approach to design. In this case a designer automatically creates basic form of elements and can adapt it to specific assumptions and does not design everything from the start.

In this paper the main aim was shown how to prepare Generative Model based on CATIA system. The full process of Generative Model preparation, from acquiring of knowledge to testing of prepared models was presented. The paper did not focus so much on knowledge engineering tasks because these tasks are described very well in other literature positions. More focus was put on how to make model in CAD software because it is a bottleneck which reduces the use of such type of models.

Acknowledgement

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Analysis of Differences Between Perpendicularity Measurements Applying ISO 1101/2012 and ASME Y14.5-2009 and Its Impacts

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Abstract. The dimensional variations inherent in a manufacturing process are the reason for the existence of the acceptance tolerance concept on a product characteristic. The geometric quotation system has many advantages over the Cartesian system by avoiding ambiguity in the interpretation on form, orientation and location errors. The two main standards that define the geometric quotation on a mechanical design are ISO1101/2012 and ASME Y14.5-2009. However there are differences in interpretation even when the same symbols are mentioned by these standards. It is, therefore, important to know these differences to ensure the quality for companies that provide products to customers who apply different standards of geometric control. This article presents the results of perpendicularity control using each standard and their difference as an example of the impact when choosing one of them. In addition, the article shows preliminary results of a still on-going survey indicating that these differences between the standards are still little known among professionals in the areas involved in Brazil.

Keywords. Tolerances, Mechanical Design, GD&T, GPS, Metrology, Perpendicularity Measurement, ISO 1101/2012, ASME Y14.5-2009

Introduction

The inherent dimensional variations in a manufacturing process is the reason for the existence of the acceptance tolerance concept on a product characteristic in order not to compromise its function. The quotation on a mechanical drawings still uses the Cartesian system to define its dimensions and tolerances. An incorrect or ambiguous quote can cause major losses in product manufacturing [1]. Cartesian system quotation allows ambiguous interpretation and for such reason the geometric system quotation is gaining prominence in mechanical industries. Currently the automotive, aerospace and oil & gas industries has given much emphasis on philosophy of GD&T, ie, Geometric Dimensioning and Tolerances.

According to NADCA Product Specification Standards for Die Castings [2], the English engineer Stanley Parker was the creator of GD&T in the 30s. However the use of this metodology only gained momentum after World War II.

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Most of the dimensioning standards used in the industry are based on ASME (American Society of Mechanical Engineers) and ISO (International Organization for Standardization) [3]. These are the main standards applied as dimensioning methodology and there are also other global standards with lower expression. There is increasing pressure to migrate toward a common international standard, but we still need to keep them and understand their differences.

Also Krulikowski and DeRaad (1999) [3] devoted a chapter in the book Dimensioning and Tolerancing Handbook to compare ASME and ISO standards related to the design. They did their work primarily with ASME Y14.5M-1994 and ISO (various standards). In the case of ISO standards, updates used vary between 1982-1997.

ASME Y14.5 and ISO 1101 standards have some similarities, but many differences are important related to how some controls are performed that generate differences in results applying both standards. Usually standards have updates on their versions. Hence, this paper considers the ASME Y14.5-2009 and ISO 1101/2012 standards. This work focuses on the difference in how the feature of size (FOS) being controlled in position or orientation is defined by each of the standards, as well as its consequences.

1. Geometric Dimensioning Control - ISO 1101 x ASME

The two systems of geometric dimensioning most known and used in the world is the GPS (Geometric Product Specification) covered by ISO and GD&T standards (Geometric Dimensioning and Tolerancing) covered by ASME.

Usually a standard is updated to solve their own problems and to avoid ambiguity. Regarding ISO, TC213 committee works on GPS standards to solve the contradictions, gaps and lack of cohesion between them. It is also mentioned by B. Grant in 1997 that it was necessary to spread the practice of geometric dimensioning and tolerancing not only with examples, but standardizing rules that define the accepted practice widely applied in a common way around the world [4]. This will lead to:

- Reduce uncertainty in the design and product manufacturing;
- Increase the productivity of engineering and production efforts;
- Increase the use of computers and other advanced technologies in design and manufacturing.

The two tolerances systems - ISO and ASME - has much in common, but are not fully compatible [4].

James Salisbury, corporate metrologist at Mitutoyo (Aurora, IL), says the difference between ASME and ISO standards are huge and experts say that only 10% to 20% of the symbols have the same meaning [5]. Even when two symbols are equal in ASME and ISO standards, often use and interpretation are different [6].

One example where the symbols are the same but with different interpretation are the orientation (angularity, perpendicularity and parallelism) and location controls (position) on feature of size.

1.1. Feature of size

Feature of size (FOS) is not mentioned in VIM 2012 (International Vocabulary of Metrology) [7]. Feature of size are simple geometries such as spheres, cylinders (internal or external) and opposite planes that can be listed with a dimension and tolerance as shown in Figure 1.

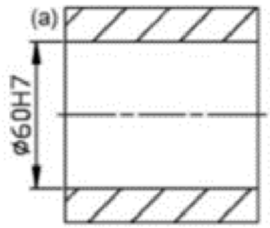

Figure 1. Example of a feature of size [4].

ISO 1101/2012 standard mention ISO 14405-1 that establish a feature of size as a geometrical shape defined by a linear or angular dimension which is a size. Size is an intrinsic characteristic of the feature of size which can be the diameter of a cylinder or the distance between two parallel planes.

In ASME Y14.5-2009 there are two types of feature of size [8]:

- Regular feature of size that is unique because:
  - Contains opposed points;
  - It may contain or be contained by an actual envelope as a sphere, cylinder or pair of parallel planes;
  - It has limits (it is not basic);
  - Follow rule number 1 of ASME Y14.5-2009.
- Irregular feature of size does not have all characteristics of a regular feature of size, so it is not under rule number 1 of ASME Y14.5-2009.

This paper only uses a regular feature of size that has similar concepts in both standards.

1.2. Orientation and location control

Feature of a part has errors inherently from manufacturing process that is not mathematically perfect. When measuring a feature we raised a cloud of points that approaches its real shape.

In ASME and ISO standards there are set criterias to find the feature of size. To perform orientation or location control, the center of the feature of size should be found.

1.2.1. ASME Y14.5-2009

Where the geometric tolerance of position, perpendicularity, parallelism or angularity is applied to a feature of size, geometric tolerance is controlling a mathing envelope of a central point, central plane or central axis of the feature by ASME Y14.5-2009 [8]. For cylinders, it must obtain the center of the largest inscribed cylinder (for holes) or the center of the smallest circumscribed cylinder (for pins). Figure 2 shows an actual cylindrical feature and the center of the smaller circumscribed cylinder of the actual feature. This center must be within the tolerance zone specified in the feature control frame to be approved.

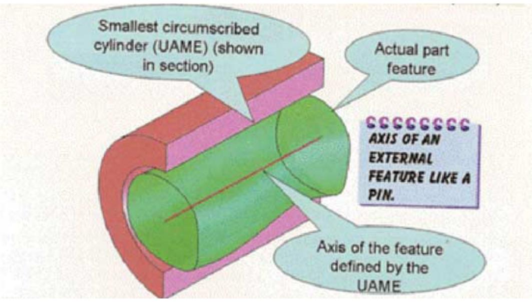

Figure 2. Obtaining the axis of a feature according to ASME Y14.5-2009 [8].

1.2.2. ISO 1101/2012

ISO 1101/2012 standard defines the extracted (actual) median line from the cylindrical feature center shall be within the specified tolerance zone. The standard specified on item 4.3 to obtaining such median line is described in the ISO 14660-1 and ISO/TS 17450-1 standards. Figure 3 shows details how this median line [9] is obtained.

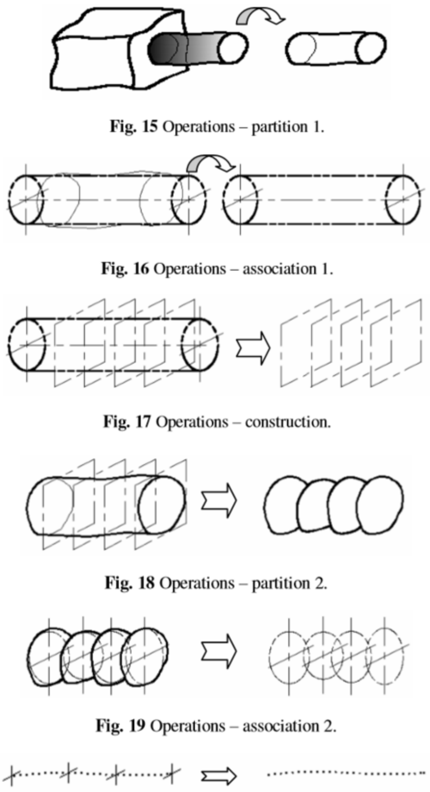

Fig. 15 Operations – partition 1.

Fig. 16 Operations – association 1.

Fig. 17 Operations – construction.

Fig. 18 Operations – partition 2.

Fig. 19 Operations – association 2.

Fig. 20 Operations – collection.

Figure 3. Obtaining the axis of a feature according to ISO 14660-1 and ISO/TS 17450-1 [9].

- Partition 1 – from the non-ideal surface model, of the non-ideal cylindrical surface
- Association 1 – of ideal feature (cylindrical)
- Construction – of planes perpendicular to the axis of the associated cylinder
- Partition 2 – of non-ideal circular lines
- Association 2 – of ideal feature of type circle
- Collection - of the centres of the ideal circles

In ISO 22432 are described various types of feature [10]. One of them is called substitute feature. It is a unique ideal feature associated with a non-ideal feature, e.g. as used in CMM techniques.

Despite the fact that ISO 1101 defines an extracted (actual) median line from a non-ideal feature, CMM apply an ideal feature associated with a non-ideal feature.

2. Methodology

2.1. Orientation and location control

In order to simplify the test, this paper shows the perpendicularity control of a round pin. However, the understanding of a perpendicularity control on a feature of size is similar to position and orientation control (perpendicularity, parallelism and angularity).

Usually the control of this type of feature is by checking its actual center in relation to the reference defined by the technical drawing.

Two parts were used with cylindrical features (pins) containing deviations of form on them. The design of the prototype is shown in Figure 4. One of the samples was made with an important deviation (~2mm) and another one with a small deviation (~0,2mm).

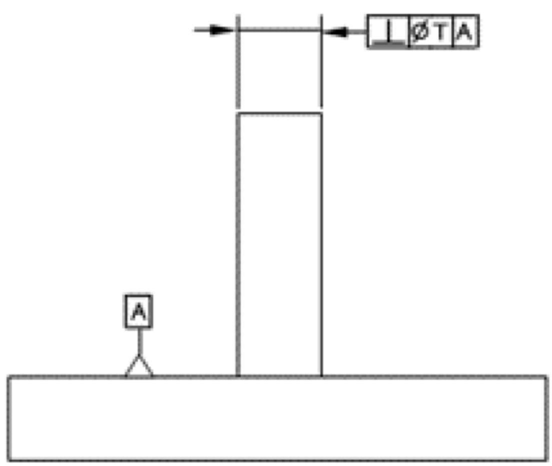

Figure 4. Prototype drawing to construct samples.

2.2. Equipments applied on tests

Four coordinate measuring machines (CMM) were applied, one at UFMG campus and the remaining at two other laboratories.

The CMM at UFMG is a TESA MH 3D 4.5.4. Last calibration was performed on 08.04.13 and presented a maximum error of (3.0 + 1,0L / 250) µm (length L in mm).

The second CMM is a Mitutoyo M Bright with valid calibration until May 2016.

The third CMM is a Coord 3 Ares, last calibration on November 23rd 2015.

The forth CMM is a Dea Scirocco. Calibration was not available.

2.3. Metodology applied on tests

XYZ points from a pin were obtained in the space that comprise the point cloud of the cylindrical feature in analysis. This cloud of points obey the following criteria:

- The cylindrical feature is divided into 5 sections and for each section are collected 6 points.
- These points are used to calculate the perpendicularity according both standards under review. The calculation was performed by the CMM´s software.

2.4. Survey related to professional knowledge differences on standards

A survey was prepared in order to know about the knowledge of professionals from development, manufacturing, metrology and education areas about the differences between ISO 1101 and ASME Y14.5 standards.

The following questions were proposed to respondents.

- What is the economic sector that you work?
- Which department do you work?
- Experience time.
- Do you apply GD&T concepts in your work activities?
- Which standard related to GD&T do you apply in your work?
- If you use both standards mentioned above, do you know the main differences between them?
- To control the orientation feature of size (FOS), do you know how each standards establish to found the feature center?

3. Results

3.1. Results on orientation control

Measurements at UFMG were performed at a temperature of (20 ± 1)°C. The equipment software does not provide a way to choose the feature of size by least squares (ISO) or the minimum circumscribed cylinder (ASME). Therefore, it's not possible to find the difference between measurements following ISO 1101 or following ASME Y14.5.

Nonetheless, the manufacturer of the CMM TESA MH 3D (at UFMG) clarifies that its software complies with ISO requirements. To measure according to ASME requirements an additional software is needed. Following contacts with the manufacturer, softwares used by their CMM´s in Brazil usually have ISO as default standard.

Measurements at the second laboratory were performed at a temperature of (22.8 ± 0.5)°C. It was observed that this CMM, as well, does not allow the measurement of orientation errors following ISO 1101 or even ASME Y14.5. The CMM´s software does not provide ways to choose the feature of size by least squares (ISO) or the minimum circumscribed cylinder (ASME). Therefore, no tests could be arranged in order to detect differences between measurement results, neither following ISO 1101 nor following ASME Y14.5.

The manufacturer Mitutoyo explains that the software used in their CMM´s complies with ISO requirements and the software version available at that particular laboratory is a version (V2.0 R3) that does not yet have the possibility to choose a feature according to ISO or ASME. The version on the CMM in question can only choose the least square average from a circunferency. To choose the cylinder by least squares averages of minimum circumscribed circles, a version 3.0 or higher is required .

Other manufacturers of CMM´s have confirmed that their machines, as well, apply ISO as default and, usually, do not provide detailed information on how to differentiate the control of orientation or location following both standards.

The two remaining CMM´s able to measure by both standarts gave the following results:

Table 1. Results on two equipments (values in mm).

		Results	
Equipment	**Calculation condition**	**Part 1 (Perp. ~0,2)**	**Part 2 (Perp. ~2,0)**
CMM Coord 3 Ares	ISO	0,2064 / 0,2111 / 0,2121	2,7711 / 2,7639 / 2,7626
	ASME	0,2044 / 0,2051 / 0,2074	2,7702 / 2,7679 / 2,7670
CMM Dea Scirocco	ISO	0,162	1,979
	ASME	0,162	1,982

Three results were obtained from Coord 3. Their mean and standard deviation are shown on table 2.

Table 2. Mean and standard deviation.

Calculation condition		**Part 1 (Perp. ~0,2)**	**Part 2 (Perp. ~2,0)**
ISO	Mean	0,2099 mm	2,7659 mm
	Standard deviation	3,0 μm	4,6 μm
ASME	Mean	0,2056 mm	2,7684 mm
	Standard deviation	1,6 μm	1,2 μm
	Difference of mean (90% confidence)	(4,2 ± 4,1) μm	(2,5 ± 5,8) μm

In this experiment the probe contacted all around the pin. However, it was impossible to calculate the orientation errors following both standards from the same collected feature points (point cloud). Hence, it was performed six times, three times for each standard, certainly inflating their respective standard deviations. Nontheless, results from Coord 3 already demonstrate significant differences between ISO and ASME, as can be verified through a single sided test of sample means (t-test with 95% [11]).

The advantage of Dea´s CMM is its ability to calculate orientation errors for both standards from the same collected feature points (point cloud). Theoretically, this allows for the best direct comparison of results. However, in the experiment with this particular CMM, only a one-sided contact of the cylinder (semi cylinder) was feasible, thus, loosing the possiblity of direct comparison of results with Coord 3 CMM.

3.2. Results on survey about knowledge on differences between standards

This survey involved a sample of 121 professionals with greater participation from the automotive sector (64%) and from the product development department (42%) as shown on Figure 5 and 6. Distribution of experience was well-balanced as shown on Figure 7.

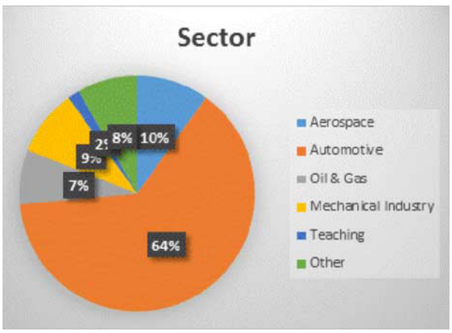

Figure 5. Sector distribution.

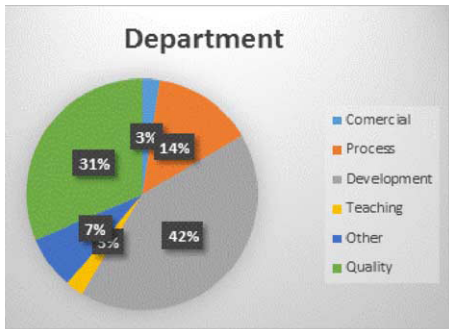

Figure 6. Department distribution.

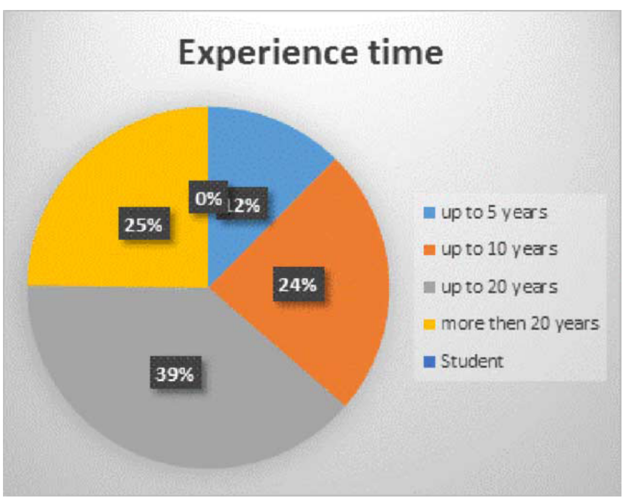

Figure 7. Experience distribution.

The survey showed that 77% of respondent professionals use GD&T in their activities. From these respondents 56% apply ASME Y14.5 and 35% apply ISO1101 as shown on Figure 8. Only 18% of the professionals who apply GD&T know the major differences between these standards as shown on Figure 9.

Figure 8. Standards applied.

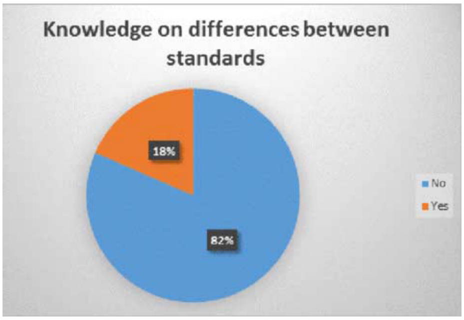

Figure 9. Knowledge on differences between ASME and ISO.

4. Conclusion

The measurements reliability is an important factor so that business transactions are made in a just and peaceful manner [12]. In addition to the uncertainties that are inherent to each measurement process, there are criterias defined by ASME and ISO standards on how to control a feature, that may add a significant contribution to the overall uncertainty. If these influences are not properly understood and, hence, not recognized, they may inflate the risk of disapproval of good parts and/or approval of bad parts.

Among the rules of geometric control, the most applied standards are ISO 1101 and ASME Y14.5. Most CMM´s apply ISO as default, however ASME Y14.5 standard is more widely applied by professionals who use GD&T.

Ignorance of the rules and their differences may generate product designs not suited to its needs. Who produces a part may misinterpret what the designer expects and quality control may disapprove good parts or approve bad parts. The precision in communication must be reassured in all departments that use a mechanical drawing within an organization and in relations between customer and supplier.

Many industry companies have a similar CMM to those applied in this experiment, i.e., small and compact. Sometimes, additional softwares are needed but often have a high cost that usually, is due to the complexity of algorithms for extracting elements as set by both standards. So what is measured today by CMM´s may often be questionable when it comes to the control of orientation or position.

In addition, a question arises regarding all CMM´s that apply an associated feature instead of the extracted feature when using ISO 1101 for the calculation of orientation errors. ISO should be updating its description of definitions or, otherwise, calculation on CMM´s should be revised.

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Process Mining to Knowledge Discovery in Healthcare Processes

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Abstract. Healthcare processes are complex and require a high-level of interdisciplinary cooperation among the different specialists and sectors involved in their delivery. Information flows among organizational entities, sectors, areas and employees represent possible low process interoperability risks as well as non-compliance risks between business rules and actual process deliveries. Besides this complexity, the Brazilian healthcare area has a notorious problem in its public and private health care systems. These problems are of structural, organizational and financial natures, reflecting the low value attributed to quality and to the actual services in recent surveys of Instituto Data Folha and the Brazilian Ministry of Health (*Ministério da Saúde*). This paper intends to propose an adaptation of Process Mining as an ancillary tool in knowledge discovery processes in healthcare in order to contribute to further improving this area in Brazil. In order to accomplish this, a case study was carried out in the Erasto Gaertner Hospital, located in Curitiba – PR, Brazil, a local reference in cancer treatments.

Keywords. Process mining, process mapping, business rules, organizational mining, healthcare.

Introduction

The healthcare area is complex and has some notorious problems of both organizational and administrative natures. These problems can be described as being related to failures in the organization model, low level of compliance between business rules and the actual processes executed and of interoperability among organizational entities, sectors, areas and staff, lack of training and knowledge by process specialists, and other organizational issues with possible impact in the correct execution of the processes. In addition to these issues, healthcare processes require high-levels of interdisciplinary cooperation and coordination among different specialists such as physicians, nurses, attendants and pharmacists. Despite all this expected interaction, it is normal to find areas working in isolation, since, in many cases, the different areas have no contact or knowledge of what is taking place in other areas. Consequently, often there is no awareness of what is happening in the delivery of health care processes for groups of patients with the same diagnosis, and it is not uncommon for groups of patients with the same diagnosis to receive different test and treatment procedures [1]. This can generate risks of low performance, increased costs and also problems of interoperability among systems and hospital areas when working together

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in the process (interoperate) to ensure effective exchange of proper, correct and sufficient information.

Brazil has a historical problem with respect to the national public healthcare system. The IDSUS (Índice de Desempenho do Sistema Único de Saúde) performance indicator is used by the Brazilian Ministry of Health to collect information on the quality of National Healthcare System – SUS (Sistema Único de Saúde) distributed in 24 indicators, of which 14 are in connection with access to services and 10, to effectiveness of services received. In the 2011 survey, on a scale of 0 to 10, the national mean score was 5.5. Another study from 2015, carried out by Instituto Datafolha on request from the Federal Council of Medicine (CFM - Conselho Federal de Medicina), heard 2069 people, of whom 93% attributed scores of bad or regular to the public and private health care services in Brazil.

These problems and their underpinning complexity make it necessary to continually monitor health care processes with a view to mitigating the risks of compliance violations, medical errors or damages to patients. Kaymak et al (2012) [2] establish that one of the difficulties in health care is the lack of consistent definitions for its processes with problems that may be listed as pertaining to medical treatment or organizational processes. Such processes are specific (peculiar) and generally display the following characteristics:

a) highly dynamic: as a result of the continuing emergence of new drugs, procedures, treatments and diseases;
b) highly complex: as a function of several factors, such as: complexity of the clinical decision-making process, large data volumes, unpredictability of patients and treatments, and other factors;
c) multidisciplinary: given the existence of a number of specialized departments, medical disciplines and health services providers; and
d) Ad-hoc: due to the high degrees of variability, lack of repetitiveness and low predictability for large scale process analysis.

The importance of having a high-level of governance in these processes is based on the characteristics of the healthcare area in Brazil which is highly regulated and under supervision of several regulatory agencies such as the Brazilian Ministry of Health, Brazilian Health Surveillance Agency (ANVISA), Brazilian Agency of Supplemental Health (ANS), Brazilian Labor and Employment Ministry (MTE) and the municipal and state departments of health. Health services establishments that are not fully compliant with regulations are liable to civil or criminal sanctions ranging from warning notices and fines to sanctions ranging from partial to complete loss of their operating license.

In the healthcare area, the use of process mining is a relatively new, and may be used in making the right clinical decision, thereby reducing costs and improving treatment quality. This has become possible due to the changes occurred in recent decades, through which most health services institutions now have operational support from a control or management system in generating logs of the different activities performed. Hospital information systems (HIS) are examples of these systems, and have aroused increasing interest in Brazil in both, public and private health service providers. The Hospital Information System deployed by the Brazilian SUS (SIH / SUS) [3] is an example of the health services management data systems available. There is also great interest in administrative software applicable in tracking the entire patient service and treatment cycle - from their first contact with reception until the moment that care and treatment are completed. All this information can provide an accurate perspective of the processes executed.

In this context, Processes Mining is important in that it is capable of, based on the event log information, automatically provide a description of the processes currently applied, and thereby generate the current flow of activities based on the models generated, enabling high-levels of knowledge on the activities performed within processes. In addition, these techniques are applicable to event logs originated by different organizations making it possible for discovery process outcomes to be obtained in relatively short timeframes, and, therefore, deployment in the healthcare area [4].

This paper targets applying process mining through organizational mining in the healthcare processes in order to obtain knowledge on organizational flows, organizational structures and social network analysis among the organizational entities. In this paper, we describe process mining and organizational mining in section 1, section 2 provides a description of the methodology proposed by this research, section 3 contains the case study applied at Erasto Gaertner Hospital and section 4 brings the conclusions.

1. Process mining methodology

The methodology used in this paper starts by considering an overview of the process mining stages comprised of discovery, conformance and extension, and focuses on the discovery of information on the organizational model through the organizational mining techniques.

1.1. Process mining

Process Mining deals with extraction of process delivery knowledge from the respective process execution logs for a wide variety of processes. According to Van der Aalst et al (2012) [5] the goal of process mining is to discover, monitor and improve the actual process delivery through the extraction of event log information and knowledge. Process mining can be used to support the redesign and diagnosis phases through analysis of the information generated in carrying out the process. Event log-based process mining is capable of automatically providing a description of the actual process, generating the activity and information flows. It is applicable to event logs and data logs generated by a wide range of systems, including those applied in healthcare systems. Figure 1 is an adaptation of the traditional process mining model presented by Will M.P. van der Aals (2008) [6] for health care processes.

Process mining has 3 (three) practical applications: 1) discovery of organizational models with a view to constructing models that reflect current situations; 2) measuring the level of compliance between the actual process deliveries and their business rules; and 3) extension which aims at enriching the actual process model by projecting the information extracted from process logs [5].

These techniques seek to achieve different types of models for different perspectives, such as the process perspective (or activity streams), the perspective of the organization and the perspective of the data generated. The type of model generated depends on the technique used. For each technique, there are specific plugins that may be used through the use of a process mining tool. An example of one of these tools is the Process Mining Workbench (ProM) an open source framework for process mining algorithms.

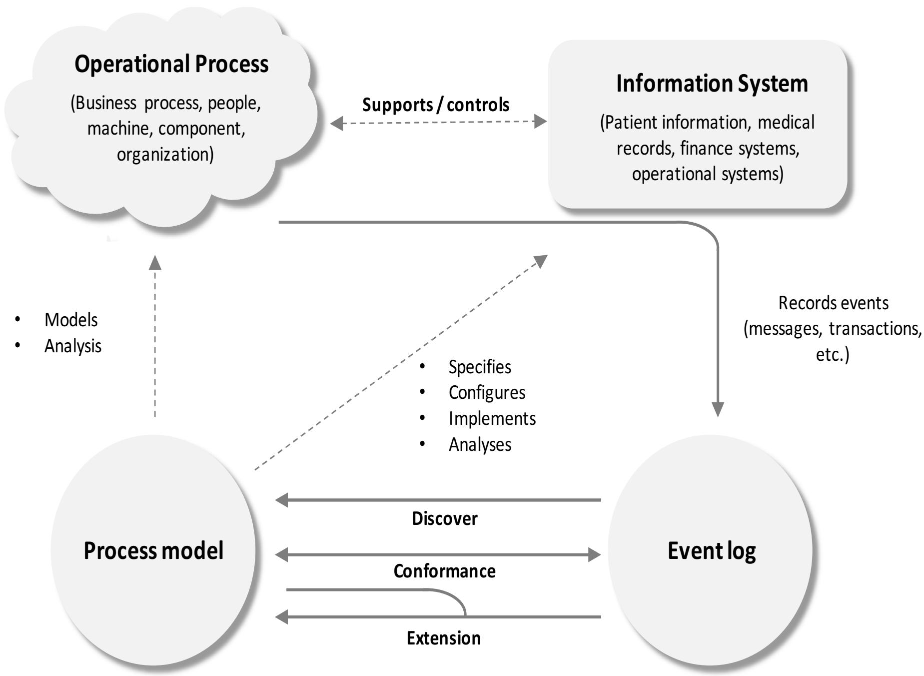

Figure 1. An adaptation of Process Mining overview (Will M.P. van der Aalst et al., 2008) [6].

1.2. Organizational mining

Organizational mining is defined as part of the discovery stage in process mining, responsible for driving understanding of the relationships between organizational entities. There are 3 (three) types of organizational mining: i) organizational model mining; ii) social network analysis; and iii) information flows between organizational entities [6].

Organizational mining is capable of grouping organizational units or rules and discovering the relationships between them. Will M.P. van der Aalst et al (2008) [6] describe that organizational model mining aims at deriving the organizational model from its process logs. By applying process logs, all the elements and interactions comprising the current process can be transcribed.

One of this transcriptions may be the social network analysis. In the ProM Tool, the Social Network plugin provides 5 (five) kinds of metrics to generate social networks - handover of work, subcontracting, working together, similar task and reassignment.

2. Proposed methodology

The use of organizational mining provides a wide range of information to inform knowledge discovery in health care processes, and can generate knowledge about the hospital's processes, such as the interactions between organizational entities and hospital staff, what types of information are exchanged and the frequency in which these information items are exchanged.

As described in Figure 2, there are 3 (three) types of organizational mining. We propose to use two of them: (a) Organizational model mining; and (b) Social Network Analysis. Information flows between organizational entities is out of scope because is used only to discover the information exchanged between entities. The Social Network Miner and Organizational Miner plug-ins in the ProM tool can be used to generate this analysis. The information obtained in this health care process knowledge discovery process will be transcribed into a comparison matrix to display the interactions discovered.

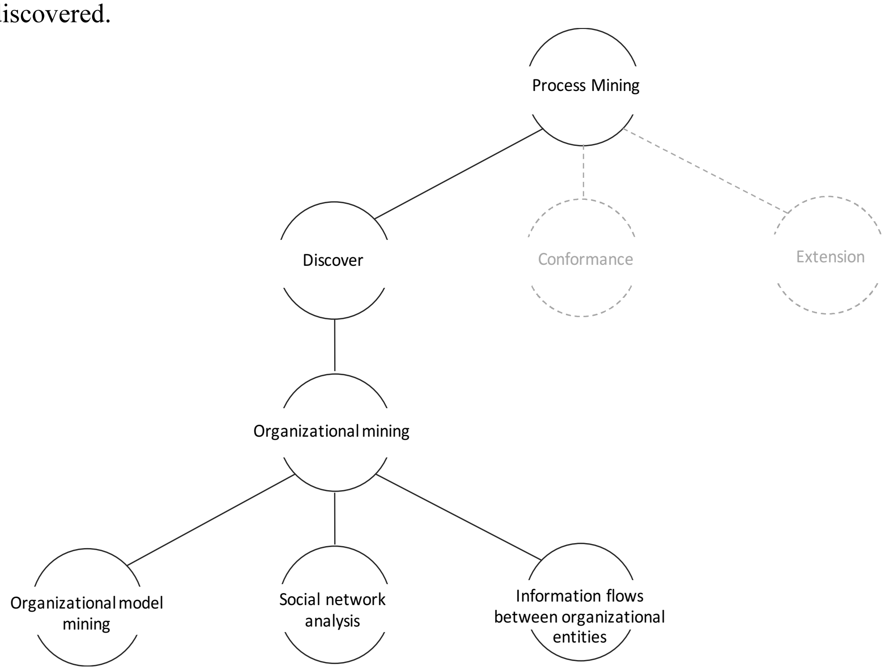

Figure 2. Representation of Organizational Mining.

Pedro Espadinha-Cruz et al (2015) [7] show the use a comparison matrix to demonstrate interactions between two tier suppliers in an automotive supply chain. This matrix represents the internal and external interactions among organizational entities. This information supports the interoperability analysis and may be generated by process mining. Healthcare processes comprise many interactions among different areas, professionals and sectors that can be represented in a comparison matrix (Figure 3).

		RELATIONSHIP AMONG ENTITIES																							
		Area 1						Area 2						Area 3						Area 4					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Area 1	1																								
	2																				X				
	3								X																
	4																								
	5							X															X		
	6										X														

Figure 3. Example of a comparison Matrix.

"X" represents the organizational entities' internal and external interactions, but does not show the power of these interactions nor the order in which they occur, for example, whether the interaction is from "A" to "B" or from "B" to "A" for an interaction between organizational entities "A "and" B ". One proposal is to replace "X" using the symbols "→", "←" and "←→" to represent the type of information exchange that occurred in the process between the two organizational entities. This analysis can provide information to support interoperability analysis, define the critical points to be monitored and the most susceptible areas and activities liable to a failure in interoperability.

3. Application of a case study at Erasto Gaertner Hospital

Erasto Gaertner Hospital (HEG) is located in Curitiba, Brazil, specializes cancer treatment. The choice of HEG is due to the large volume of patients treated. In accordance with the HEG numbers, 310,895 patients were addressed in 2015, generating 1,364,532 patient care procedures.

For this survey, the process selected is chemotherapy treatment. Since the focus is on the patient, the goal is to analyze the path taken by the patient in following the hospital processes, from their first contact with the hospital until the completion of the treatment.

The process support system is Philips Tasy, which was not designed to reflect process dynamics, but was designed for deployment as a data store. Thus, it was necessary to ask the hospital technology team to raise the data needed to draw the path taken by the patient in the process, as described in Table 1.

For this study, a sample of 67 (sixty-seven) patients was requested with the respective database being extracted from Philips Tasy. The data can be then read using a primary key perspective whereby a key enables discovery of the activity flows covered by the patient in the process. Then the extracted base format had to be converted from XLS to XES which to achieve compatibility with the ProM tool. The XES format is an XML-based standard for event logs and can present a wide range of information, including the format for each data item displayed as a timestamp, strings and numeric information.

In the PROM tool, a wide range of information is generated using the log imported, such as the number of processes, cases, events, event classes, event types and originators. PROM supports a wide variety of plug-ins and mining algorithms, such as the Compliance Checker, Organizational Miner and Social Network Miner. The Compliance Checker allows a fitness index between control process model and actual process model to be obtained, perform a structural analysis of the process executed measuring the amount and consumption, production losses, and process instances that, for some reason, were not completed. The Social Network Miner and Organizational Miner provide information enabling discovery of the interactions occurring between organizational entities. All this information provides an adequate level of knowledge about the relationship between areas, activities, resources and data shared within the process.

Table 1. Data extracted from Tasy System to compose the process log.

Field	Type	Description
Patient ID	Numeric	Patient identification number in the Tasy system
Medical Records ID	Numeric	Medical record number linked to Patient ID
Age	Numeric	Patient age
Sex	String	Male or Female
Treatment type	String	Public (SUS) or Private (health insurance)
Registration date	Date/Time	Date that the register was included in the system
User ID	Numeric	User ID number used to register the information in the system
User Profile	String	User profile linked to User ID used to input user information in the system
Medical specialty	Literal	Medical specialty that originated the service/treatment received by the patient
Date of the activity	Date/Time	Date on which the activity was performed
Activity	String	Description of the activity performed (reception service, medical care, chemotherapy treatment, etc.)
Activity specialist	String	Description of the specialists involved in the execution of the activity

The Organizational Miner identified 37 (thirty-seven) interaction areas related to 11 (eleven) clinical care procedures. The interactions that occur are represented by a connection between the areas and medical specialties enabling the interactions occurring within the process to be established.

In the Social Network miner, several techniques can be applied in analyzing the social networks in the process. Van der Aalst et al (2005) [8] say that social network analysis refers to the collection of methods, techniques and tools in socio-metrics targeted at analyzing the social networks. in order to analyze the relationship among organizational entities, social network analyses were applied, as described in Figure 4.

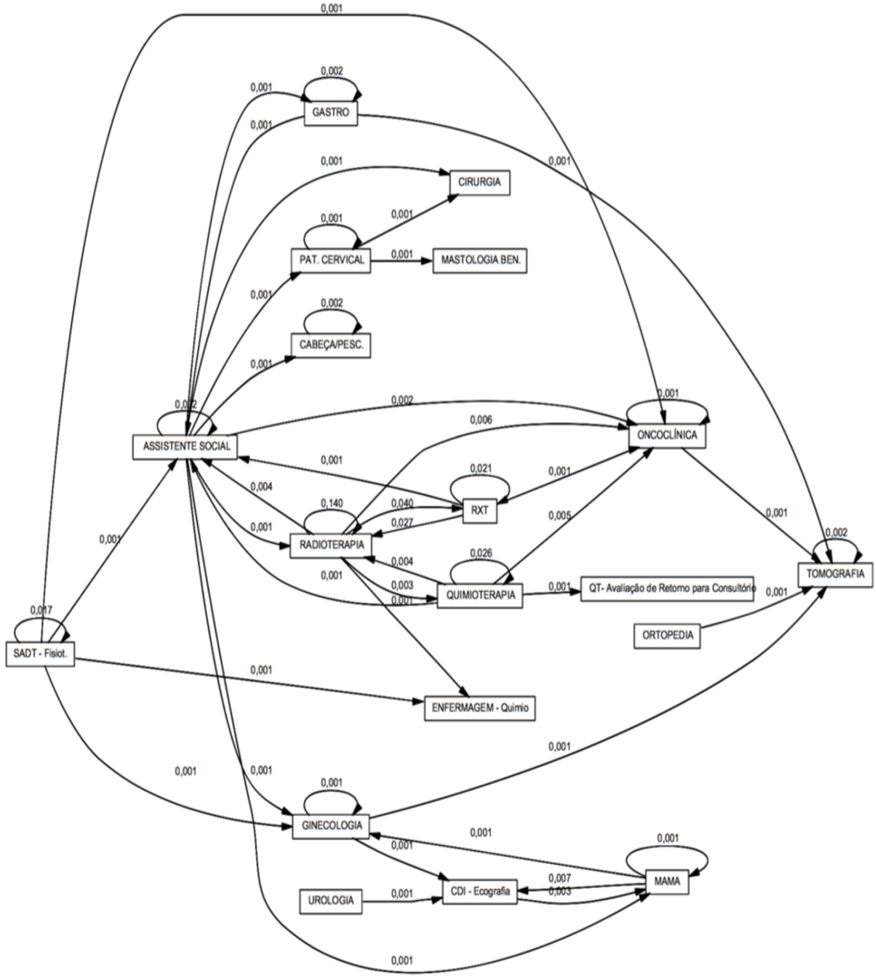

Figure 4. Social graph drafted based on social Network analysis of the event log.

By applying the organizational mining plug-in, information about the organizational structure, organizational entities carrying out similar tasks and organizational entities working together was obtained. An example of organizational mining results is described in Figure 5. Based on this information, a wide range of interaction maps can be generated and display, for instance, the interaction between organizational entities shown in Figure 6.

All the interactions occurring in the process were mapped by applying a comparison matrix. This led to the discovery that the areas with more interactions are Caseworkers (12 interactions), Oncology Clinic (7 interactions), Gynecology and Radiotherapy (6 interactions each). These areas are more likely to have process failures, given the high level of interoperability involved. Poor interoperability among these areas in the exchange of information could adversely impact the entire process.

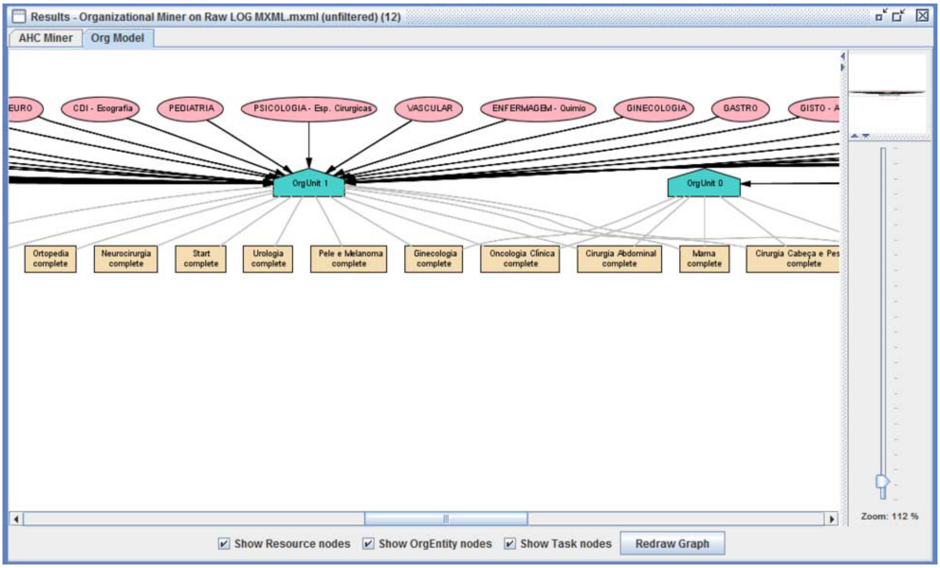

Figure 5. Organizational mining result.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	# Interactions
ASSISTENTE SOCIAL	1	←→	→		←→		←→	→	→		→		→		←	←→	←	←			12
CABEÇA/PESCOÇO	2	←	←→																		2
CDI - ECOGRAFIA	3							←	←→											←	3
CIRURGIA	4	←→											←								2
ENFERMAGEM	5															←		←			2
GASTRO	6	←→					←→												→		3
GINECOLOGIA	7	←		→				←→	←									←	→		6
MAMA	8	←		←→				→	←→												4
MASTOLOGIA	9												←								1
ONCOCLINICA	10	←									←→				←	←	←	←	→		7
ORTOPEDIA	11																		→		1
PAT. CERVICAL	12	←			→					→			←→								4
QT - AVALIAÇÃO DE RETORNO	13														←						1
QUIMIOTERAPIA	14	→									→			→	←→	←→					5
RADIOTERAPIA	15	←→				→					→				←→	→	←→				6
RXT	16	→									→					←→	←→				4
SADT. FISIOT.	17	→				→		→			→							←→			5
TOMOGRAFIA	18						←	←			←	←							←→		5
UROLOGIA	19			→																	1

Figure 6. Comparison Matrix.

4. Conclusions

During The 6 (six) months of fieldwork in HEG, the adequacy of process mining in the healthcare area was tested. The use of process mining is possible due to the flexibility it provides for a variety of different processes. The results generated can be used to inform decision-making and solve problems identified in the process.

In this paper, organizational mining was deployed within the context of healthcare processes. It was possible to map all interactions occurring in the process, and define areas with the highest numbers of interactions. These key areas, which relate to a larger number of areas, are more susceptible to failures in interoperability, making it necessary to monitor processes in order to prevent failures in delivery. The Caseworker area interacts with 66% of all areas involved in the process, followed by Oncology Clinic (39%), Gynecology (33%) and Radiotherapy 33(%).

The next goal of the research is to extend this model to other processes in different hospitals focusing on obtaining a larger sample and testing the strengths and weaknesses of process mining in healthcare applications, discovering and measuring the information that is exchanged between areas and mature this methodological approach to other processes and hospitals, in order to improve the service and quality of medical and hospital care delivered in both, public and private hospitals, reducing costs and improving revenue.

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OntoIRBR: Ontology for Information Retrieval in Bibliographic Resources

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Abstract. The advancement of corporate systems and accelerated production data and information using different technologies bring the challenge to managers: the problem of how to integrate and relate the content generated by turning it into knowledge. Alternatives to this are the storage, retrieval systems and organizational content management, leaving the challenge of interoperability and standardized structure of the relationship between the document and its contents and content between different documents. In this context this article presents the proposal of an ontology, conceptual representation for information retrieval in bibliographic resources called OntoIRBR (Ontology for Information Retrieval in Bibliographic Resources). This ontology has structural elements and document management integrators associated with content management in order to enable the classification of information associated with the classification of document types and metadata.

Keywords. Ontologies. Information Retrieval. OntoIRBR.

1. Introduction

The management of information and knowledge generated in organizations is a growing demand today. The advancement of corporate systems and accelerated production data and information using different technologies bring the challenge to managers on how to integrate and relate generated content, transforming it into knowledge. Alternatives exist to support the solution, such as storage systems, recovery and organizational content management, including the EDM system (Electronic Document Management) and ECM systems (Enterprise Content Management).

The treatment of content requires relevant information so that the contents can be recovered easily and user needs are met.

Thus, it is very important that metadata related to the elements recorded in these systems enable a search for quality, and also allow not only the recovery of data or specific information, but relate the same data or information with other elements relevant to the research, enabling the effective use of the knowledge acquired.

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The creation of a structure that allows content to be related to another from well-defined classes and relationships, can contribute to the development of knowledge-base systems, improving the experience of users recover data and information, and finally allowing the upgrading of generation of knowledge.

In this context this article aims to present an ontology, conceptual representation for information retrieval in bibliographic resources. This ontology was named OntoIRBR (Ontology for Information Retrieval in Bibliographic Resources). The proposal is a basic structure of an information retrieval ontology developed using the CmapTools and Protégé software, each according to the stages of development.

2. Concepts

For this paper the two essential concepts to the topic were analyzed, they are: ontologies and information retrieval.

2.1. Ontologies

Ontology can be understood as the representation of a conceptualization with their specified on a given domain [1] or a formal and explicit specification of a shared conceptualization [2]. Deepening the understanding of the term, Kiryakov [3] and Rautenberg [4] clarify that an ontology is the relationship between the four elements, which are: classes, relations, instances and axioms. Classes, the group that represents the concepts in a given field of interest; Relations, would be the set of relationships or associations between domain concepts; Instances are related to the set of instances derived of classes, or the examples of concepts represented in an ontology; and finally the axioms, which are the domain axioms sets; these serve to model restrictions and rules inherent to instances.

As the hierarchical classification, the ontologies can be classified as high-level, domain and task, and application. The high-level ontology is the one that aims to describe general concepts, such as land, people, space. The domain ontology and task describes the general concepts of a domain, for example, "highway " in transport. Finally, the application ontology depends on domain and task ontologies, because it describes an application that includes the roles of entities in a domain in the execution of an activity [4][5].

Ontologies can also be understood as a technological translation structure, or a tool to be used for the representation of knowledge in database, vocabularies and thesaurus, for example [6].

The relation of ontologies with the information retrieval process is fruitful, because with its use, expands the possibilities of content organization and access to information in systems. That is, the use of ontologies allow to go beyond the indexers elements (vocabularies and thesaurus documentaries) [7].

2.2. Information Retrieval

The retrieval of information can be understood as the process of acquiring information according to the structure available and necessary for the professional information and / or user structure, commonly related to the search for information.

This process involves the representation, storage, research and search for information in a relevant manner to the applicant information [8].

Ingwersen [8] presents a simple model of information retrieval that involves representation, matching function and query (Figure 1).

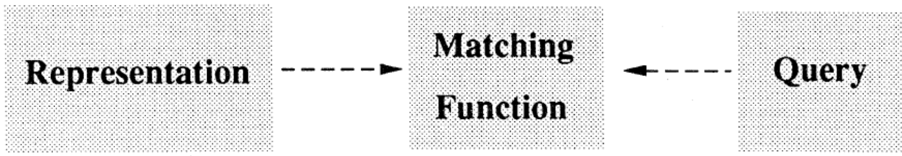

Figura 1. Simplest model for information Retrieval [8].

Information retrieval can also be found in the literature as a subarea of information science "that study the storage and automatic document recovery, which are data objects, usually texts" [9].

An information retrieval system includes documents, query generating elements formulated by users from their needs, the process of recovery, and the recovery itself of the documents forming a list of documents considered relevant; these documents are retrieved from the data structures and formulated query [9].

Of information retrieval classic models have the Boolean, vector and probabilistic presenting search strategies of documents relevant to a query, according to Cardoso (2000, p.2) being:

• The boolean model meets a query logical expression retrieving documents containing the terms used in the query; a query using a Boolean expression commonly contains the logical connectives AND, OR and NOT.

• The vector model represents the documents and queries as terms of vectors, where the terms are unique occurrences in the documents, so the documents returned as a query result are represented by similarity, being the result of this consultation product of a calculation of similarity.

• The probability model describes binary documents by assigning weights representing the presence or absence of terms in this document; so that the documents returned as a result of this query are the product of a probability calculation that the document is relevant to the calculation performed query.

The organization of information and its recovery are elements of the same process being an organization of poor data imply a recovery of low relevance information; therefore it is important that the entry of data and structuring is performed according to need that want to recover [10].

For this paper is considered the recovery of information a process that is to bring the information according to the structure required for its use, from an information retrieval system that includes documents, elements to a query made by users from their needs, Process recovery and the recovery itself of documents forming a list of documents considered relevant [8] [9].

3. OntoIRBR

The proposal of an ontology for information retrieval in bibliographic resources of the need for structure and organization to optimize access to the content of bibliographic resources in digital media.

The OntoIRBR aims to serve as a representation mechanism, classification and organization of content for different types of bibliographic resources, and allow the relationship between them and their contents.

The OntoIRBR presented in this paper was based on research in engineering and management knowledge which had the main objective to identify, extract and classify knowledge elements in documents; from this initial research has evolved to a conceptual representation with other elements inherent in modeling of ontologies and necessary elements of information management and document management.

The skills previously observed for the developed ontology were, among others:

• Categorization of textual elements; and

• Main sources of information used in technical or scientific documents.

Of the questions raised in accordance with the observed skills has been, among others:

• Which are the main authors used to compose the technical report “x”?

• Which library resources are used by researchers or project technical?

• What author gives source to particular table?

• What information gives source to a particular chart?

That it sought way develop an ontology for (scope) 1) document content representation, 2) classification and association of content to documents, 3) classification elements and document management.

From the skills, issues and scope it was developed a conceptual design of the ontology (Figure 2).

From the conceptual design ontology was developed using Protégé software.

For presentation of ontology in this paper will be of object description of classes, relationships and listed instances for each of the three elements of scope.

3.1. Representation of content

The first class developed for content representation refers to the classification of bibliographic resources considered in this modeling. For this representation the class was created *“BibliographicResource”*, containing the following classes:

- Article
- Book
- Research Report
- Technical Report
- Thesis

The classes for modeling the content of representation were considered the content types defined from the analysis of bibliographic resources. How content types were found exclusively textual elements , such as tables , graphs, charts , it could be listed as source or product from another bibliographic resource or database.

Of content types were considered:

- Graphic
- Table

- Picture
- List
- Map

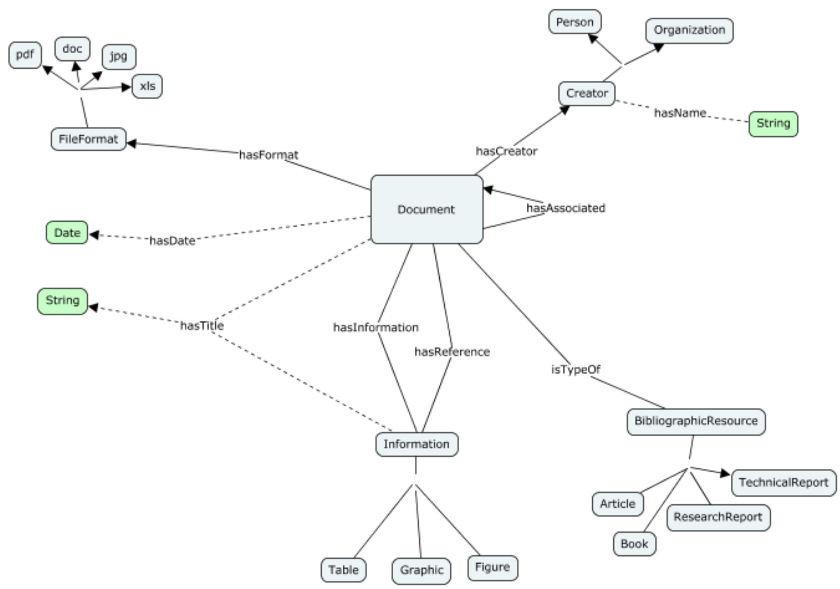

Figura 2. Conceptual ontology design

These content types have been assigned to a class named “*Information*”. These contents still received the classification according to the possible file format for the content is extracted from the bibliographic resource, class “*FileFormat*”.

The formats observed for the types of content were:

- editable text formats (ex. .odt .doc. .docx)
- spreadsheet format (ex. .calc .xls .xlsx)
- Image Format (ex. .png .jpg)
- non-editable text format (ex. .pdf)

The bibliographic resources are also given the same classification.

Each bibliographic resource or information is related to a document, class “*Document*”.

The listed links to the defined classes were:

- hasFormat: where all bibliographic resource or content has a format (file). Relationship between classes “*Information*”, “*Document*” and “*FileFormat*”.
- hasInformation: where every document is an information . Relationship between classes “*Document*” and “*Information*”.
- hasReference: where all document and information has a reference. Relationship between classes “*Document*” and “*Information*” with other “Document” or “Information”.

- isTypeOf: where every document is a type of bibliographic resource. Relationship between classes "*Document*" and "*BibliographicResource*"
- hasAssociated: association between documents. Class relationship "Document" between.

3.2. Classification and association of content

The content classification is given by the classes belonging to the class "Information" where content is classified based on the types of content of a bibliographic resource. Of content types as shown above you have:

- Graphic
- Table
- Picture
- List
- Map

These types of content are related to a bibliographic resource through class "Document" and turn the class "Document" is a type of bibliographic resource through class "BibliographicResource" (Figure 3).

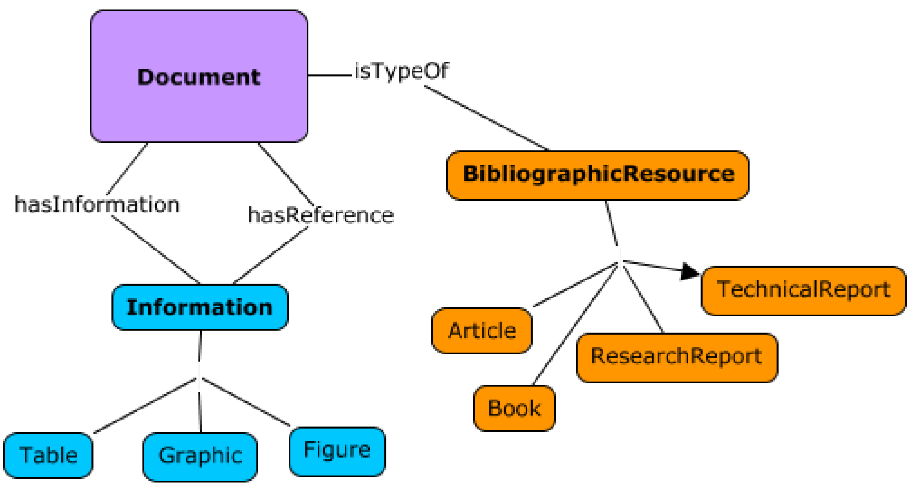

Figura 3. Relacionamento entre informação e recurso bibligráfico.

Each information is related to a document through the link "*hasReference*", and all related document is an information through the relationship "*hasinformation*".

Likewise every document is related to the type of bibliographic resource through the relationship "*isTypeOf*" (Figure 3).

The relationship between documents and information from one document to another document is given from the relationship "hasAssociated " (Figure 4).

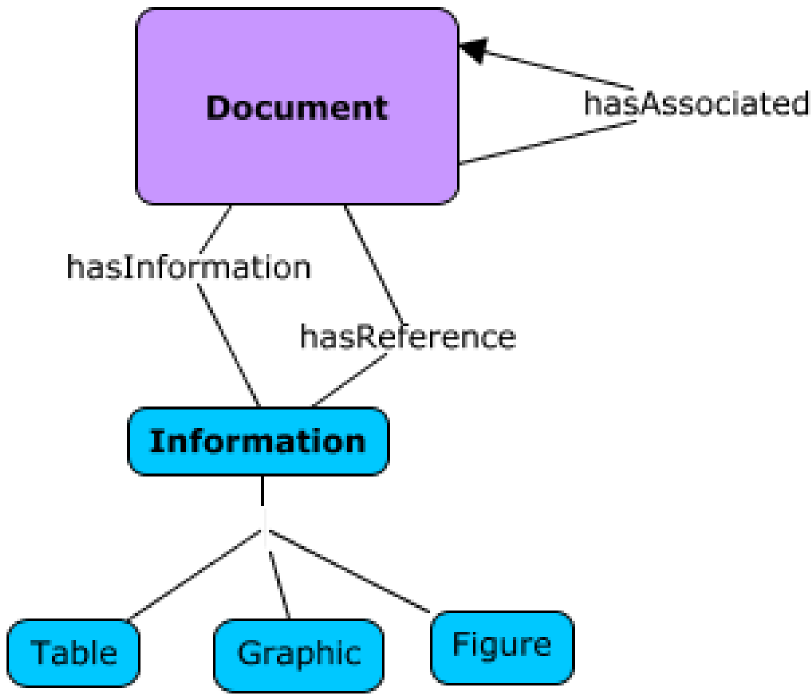

Figura 4. Relationship between documents and information between documents.

That way an information whose source document other than that to which it belongs (for example, table x from document A has as it source the spreadsheet Y of document C) it may have represented this relationship using the class "Information" and "Document" by a relationship of association.

3.3. Classification and management of bibliografic resources

The modeling of the elements related to data ownership and management of bibliographic resources aimed to bring elements that could bring a minimal description of the bibliographic resource, this way was chosen by elements representing the format, date, title and author.

For the format element, as explained above was created the class "FileFormat", this class related to class "Document" by the relationship "hasFormat".

For authorship was created the class "Creator" where the following elements were further classified:

- People: associated with authoring made by a person; and
- Organization: autorship related to an organization or institution.

This class relates to the class "Document" from the relationship "hasCreator", and has a data property relations associated with the name of authorship called "hasName" of type "string".

The "Document" class has a given property related to the date of the document called "hasDate" of type "Date".

This class has given another property called "hasTitle" of type "string" associated with the document title. This data property is also related to the class "Information" designating the title information. Finally to model presented in this paper were instantiated individuals of the class for relationship testing and verification of consistency of the developed ontology ; as an example in Figure 5 shows the individuals of the class "Document".

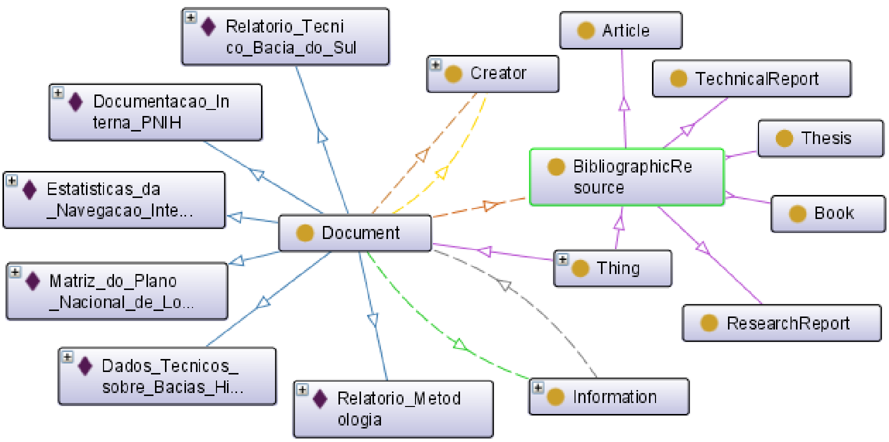

Figura 5. Example of individuals of the class "Document" and their relationships.

Figure 6 shows the individuals of the class "Information" in their subclasses "Graphic", "Table" and "Picture".

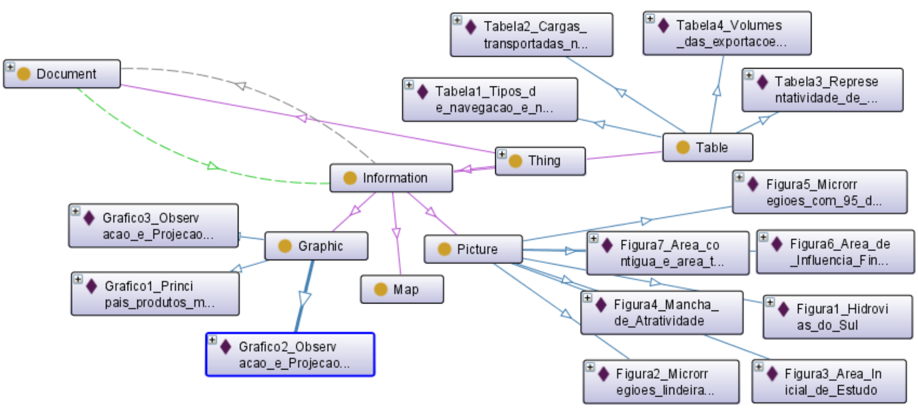

Figura 6. Example of individuals in class "Information" and their relationships.

4. Conclusion

This study aimed to present a proposal for ontology for information retrieval in bibliographic resources with a set of classes and relationships that include a set of elements required for information retrieval and content classification.

The proposed model for information retrieval sought to present a conceptual representation of the relationship between the content of bibliographic resources and their respective source document or in which it is contained.

This representation also presents descriptors for information retrieval purposes associated with authoring, format, type of bibliographic resource, document title and the content and date of the document.

This representation still lacks a set of additional elements related to metadata and specific classes for its application, but contributes to the modeling of a important field of knowledge to the present day which is the retrieval of information.

In addition, the contribution of this paper is the classification of content and the relationship of that content to the source or the bibliographic resource in which it is contained, enabling the configuration of a network of information with reference to consultation, recovery and relationship of the various types of information and documents used in a particular application.

The next step in the research is to apply the OntoIRBR in a use case with multiple files and test information retrieval methods, for example using the SPARQL language.

The authors also plan to conduct a systematic review of the literature to critically evaluate treated studies on the subject and see if the issues raised in the construction of this model are in agreement, and possibly make improvements as well as an extension of this proposed model.

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A Product Conceptualization Strategy Based on Crowd-Innovation

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Abstract. In this work, a product conceptualization strategy based on crowd-innovation is proposed consisting of two sub-systems: crowdsourcing concept generation and collection sub-system (CCGC), and concept screening and evaluation sub-system (CSE). Specifically, a crowdsourcing development approach based on neuro-fuzzy network is established in CCGC with careful considerations regarding target analysis and task allocation. An improved concept evaluation and selection approach based on domain ontology and fuzzy clustering is established in CSE for dealing with crowdsourcing results more efficiently. To illustrate the proposed strategy, a cased study of future PC design was presented.

Keywords. Product conceptualization, Crowdsourcing, Neuro-fuzzy network, Domain ontology, Fuzzy clustering

Introduction

Product conceptualization has a critical role in new product development. Thus, achieving a competitive edge at the front end could lead to more opportunities for successful final products. However, to realize product innovation in the conceptual design stage is challenging. The incomplete and fuzzy nature of this phase causes difficulties in creating a reliable innovation environment. To tackle this problem, a possible solution is to involve external resources and obtain contributions from multiple facets. Crowdsourcing with the potential of utilizing the dispersed knowledge distributed among the crowd for creativity has recently been recognized. Therefore, this study seeks to contribute to the utilization of crowdsourcing in product conceptualization for fostering innovative designs and for advancing the research in this field.

However, the integration of crowdsourcing in product conceptualization is complex. Firstly, crowdsourcing currently offers only a basic conceptual scheme to connect assigners and contributors and lacks systematic management to obtain effective entries with guaranteed quality. Secondly, product conceptualization consists of a series of consecutive activities, e.g., concept generation and concept evaluation. Therefore, the integration of crowdsourcing should simultaneously consider each design stage. Thirdly, crowdsourcing responses are often in large numbers and in various formats, which lead to further difficulties in dealing with the crowdsourced

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conceptual designs. Specific issues such as how to incorporate crowdsourcing to facilitate concept generation and how to implement concept evaluation and selection in an efficient and effective manner have to be addressed well.

Therefore, the objective of this research is to realize a product conceptualization strategy for facilitating product innovation in a crowdsourcing environment.

1. Overall research framework

Two sub-systems are developed to realize the proposed product conceptualization strategy in crowdsourcing environment (PCSCE). In particular, crowdsourcing concept generation and collection (CCGC) as a knowledge-intensive concept creation and collection process is studied as the preliminary knowledge acquisition sub-system. Concept screening and evaluation (CSE) for identifying promising innovative design concepts is studied as the knowledge processing sub-system.

For CCGC, a primary concern is to establish an online crowdsourcing platform. To realize this purpose, two aspects need to be considered. Firstly, an in-depth analysis of the innovation targets is necessary. The purpose is to drive project assigners to clarify their design requirements completely. Secondly, a deliberate task allocation process is required to effectively control the participation process without comprising the openness and freedom of idea contribution.

For CSE, the capability of crawling web pages and capturing web content is needed, since the concepts are collected through CCGC (i.e., an online platform). Moreover, textual pattern recognition, meaningful information retrieval, and tokenization could help in the preliminary processing of the extracted rough document elements. Concept reconstruction is considered to improve the comparability of crowdsourced concepts by structuring them into a unified format. Moreover, a proper decision-making strategy is needed to identify the promising concept candidates.

2. CCGC: Knowledge Acquisition Sub-system

2.1 Target analysis

To decompose the design goal hierarchically and organize these features systematically, a hierarchical architecture is established, as shown in Fig. 1 [7]. Overall, the design goal is analyzed from the following aspects: target participants, product features, and creativity space. In every aspect, specific dimensions/features are derived. Products in different categories may have very different features to be considered. The very specific features or dimensions need to be identified according to the requirements of different projects.

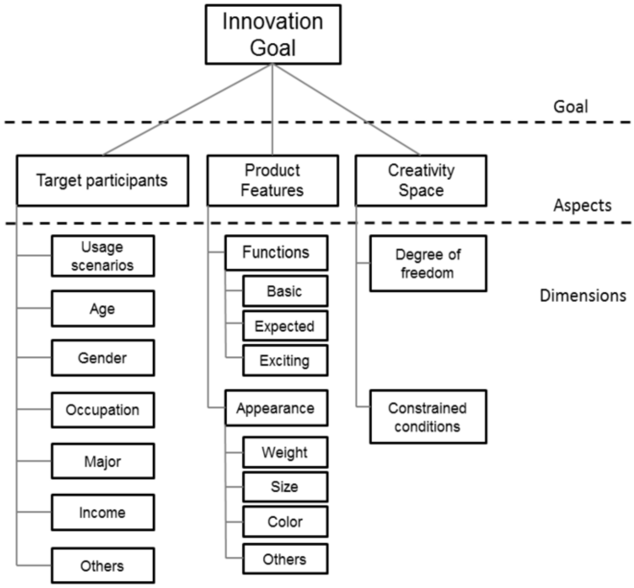

Figure 1. Hierarchical structure of target analysis.

2.2 Neuro-fuzzy HIT allocation

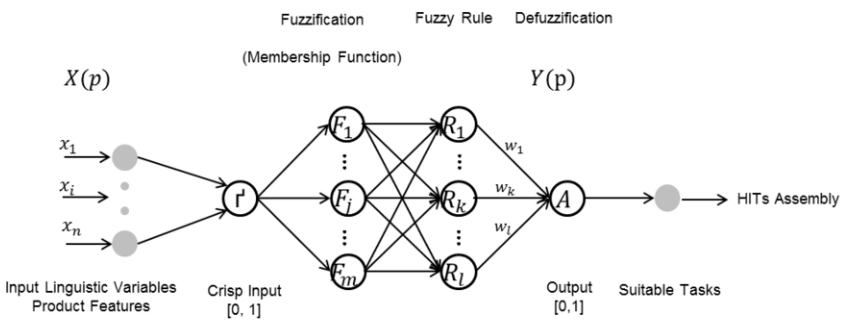

Figure 2. Task Allocation – A neuro-fuzzy network [1].

Considering the inputs (viz. the product features to be designed) and the output (viz. suitable tasks), they are often described using linguistic terms such as “very complex” or “highly difficult.” To deal with the qualitative descriptions, fuzzy methods are adopted as a suitable way for dealing with linguistic variables (as depicted in Fig. 2). Through a neuro-fuzzy process, qualitative description of the requirements on product features could be transferred to particular importance value, and tasks with corresponding importance can be assigned accordingly.

3. CSE: Knowledge Processing Sub-system

3.1 Information Extraction

A combination of web mining and text mining is proposed to extract useful information from online crowdsourced design concepts. In particular, web mining is applied to crawl web logs and extract meaningful contents from the initial online crowdsourced concepts. Text mining is applied to discover textual patterns and to analyze the textual information in a quantitative manner.

3.2 Concept Reconstruction using Design Knowledge and Domain Ontology

3.2.1 Establishment of Concept Development Hierarchy

To construct textual tokens into a proper frame according to design knowledge and principles, concept development hierarchy (CDH) is developed to represent the designers' knowledge in a hierarchical structure (Fig. 3).

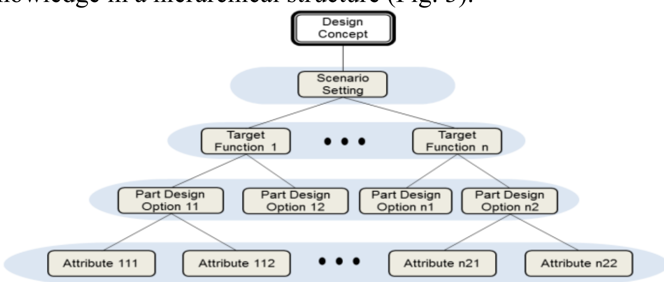

Figure 3. Concept Development Hierarchy.

3.2.2 Reconstruction of Concept Frame using Extended Ontology

Based on domain ontology and CDH, the tokens extracted from crowdsourced design concepts can be related to one another from the semantics perspective and can be structured referring to the CDH from the design perspective.

a) Develop an extended CDH (Fig. 4)

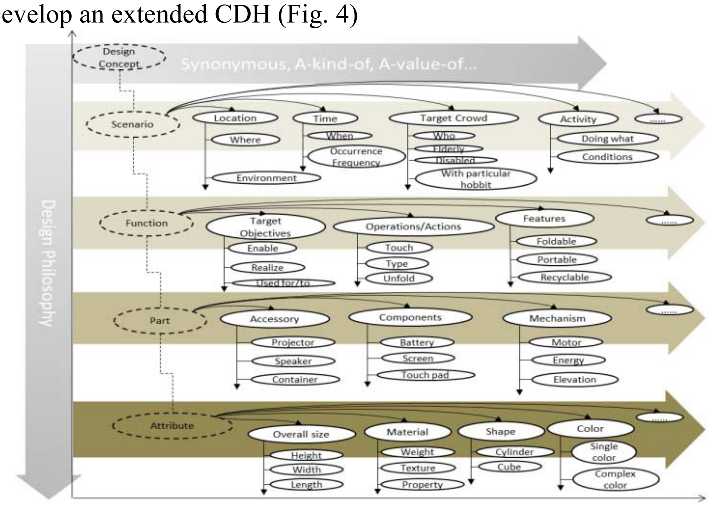

Figure 4. Extended Design Knowledge Hierarchy [8].

b) Select proper semantic relations with higher importance.

c) Build semantic connections: it is a two-directional mapping and connecting process. WordNet is used to identify synsets [2].

c1) For the "y-direction layering," Step 1: Individual tokens extracted from design concepts and the linguistic labels derived from the CDH are mapped to the lexical database. Step 2: The associated semantic relations between the mapped words which have been defined in the lexical database are identified. Step 3: The identified semantic relations are used to explore suitable connection types between the tokens and linguistic labels. Step 4: The most suitable connections are utilized to define the relations between the tokens and linguistic labels, and the tokens will be placed at the level where the linguistic labels are successfully related to them.

c2) For the "x-direction netting," Step 1: The tokens at the same CDH level are mapped to the lexical database to find the corresponding words. Step 2: The defined relations between the mapped words in the lexical database are identified. Step 3: The relations are used to identify the suitable connections to relate these tokens. Step 4: Once the most suitable relations are identified, these tokens can be connected to each other.

Design concepts in a unified structure. The individual tokens extracted from the design concepts are organized in a unified structure, as shown in Fig. 5.

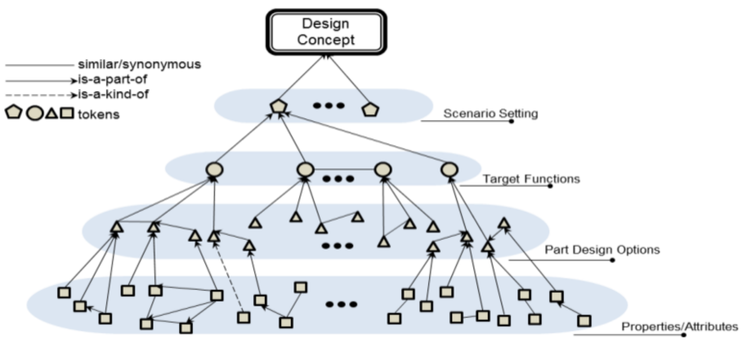

Figure 5. Design Concept in a Unified Structure [8].

3.3 Concept Clustering and Selection

3.3.1 Similarity measurement

Generally, one design concept can be treated as one document. The whole dataset can be represented as a collection of word tokens extracted from each document, as follows.

$$\phi:\left\{w_{t_1,C_1}, w_{t_2,C_1} \cdots w_{t_{n_{C_1}},C_1}, w_{t_{n_{C_1}+1},C_1}, w_{t_{n_{C_1}+2},C_1} \cdots w_{t_{n_{C_1}+n_{C_2}},C_1}, \cdots\right\}$$

where $w_{t_i,C_j} = tf - idf(t_i, C_j) = tf \times idf$ is the *TF-IDF* weight of textual token t_i in concept document C_j; tf is the term frequency of indexing term in document; $idf = \log(N/n)$, N is the number of documents in the datasets, and n is the number of documents in which the term appears.

Every design concept can be regarded as a set of word tokens. All the textual tokens are divided into three subsets as shown below.

$$C = \left[w_{t_1}, w_{t_2}, w_{t_3} \cdots w_{t_{\tilde{m}}}\right] = \left[(w_{t_1,tf}, w_{t_2,tf} \cdots w_{t_{m_{tf}},tf}), (w_{t_1,do}, w_{t_2,do} \cdots w_{t_{m_{do}},do}), (w_{t_1,pa}, w_{t_2,pa} \cdots w_{t_{m_{pa}},pa})\right]$$

The estimation of concept similarity can be regarded as a multi-dimension problem:

$sim(C_1, C_2) = (sim_{tf}, sim_{do}, sim_{pa})$

Among these measures, cosine distance is commonly used in text/document clustering [3, 4]; hence, it is utilized in this study.

$$sim_{tf}(C_1, C_2) = \cos(C_1, C_2) = \frac{C_1 \cdot C_2}{\|C_1\|\|C_2\|} = \frac{\sum_{j=1}^{n_{C_2}}\sum_{i=1}^{n_{C_1}} w_{t_i,tf,C_1} * w_{t_j,tf,C_2} * (\overline{t_i} \cdot \overline{t_j})}{\sqrt{\sum_{i=1}^{n_{C_1}} w^2_{t_i,tf,C_1}}\sqrt{\sum_{j=1}^{n_{C_2}} w^2_{t_j,tf,C_2}}} \tag{1}$$

where $\overline{t_i} \cdot \overline{t_j}$ is the term correlation

Term correlation can be obtained by estimating the semantic relations. Two parameters are important for measuring relatedness: path length l and depth h.

$$TermCorrelation = \overline{t_i} \cdot \overline{t_j} = f_1(l_{SRT}) \cdot f_2(h_{SRT}) \tag{2}$$

where l_{SRT} is the shortest path between terms in semantic relation; h_{SRT} is the depth to terms' common parent node in semantic relation.

With regard to f_1, it can be considered as an extension of Shepard's law [5], which is a commonly used measure to resolve the issue of estimating relatedness through path tracking in a hierarchy [3, 5]. Therefore, f_1 is defined as:

$$f_1(l_{SRT}) = e^{-\alpha l_{SRT}}; \quad \alpha \in (0,1) \tag{3}$$

For f_2, the depth function [3, 6] is useful to describe the observation

$$f_2(h_{SRT}) = \frac{e^{\beta h_{SRT}} - e^{-\beta h_{SRT}}}{e^{\beta h_{SRT}} + e^{-\beta h_{SRT}}}; \quad \beta > 0 \tag{4}$$

With reference to the depth function, the measurement of the overall concept similarity should take into account the influence of the CDH hierarchical depth. Thus, the overall concept similarity can be obtained by integrating the similarity at three layers, as shown in (5).

$$sim(C_1, C_2) = sim_{tf} \cdot f_{2tf}(h_{CDH}) + sim_{do} \cdot f_{2do}(h_{CDH}) + sim_{pa} \cdot f_{2pa}(h_{CDH}) \tag{5}$$

where h_{CDH} is the depth to the root node in the concept development hierarchy (CDH).

3.3.2 Fuzzy c-means clustering

Based on the similarity, concepts are clustered by fuzzy c-means clustering.

1) Choose c initial cluster centers (centroid).
2) Compute point-to-cluster centroid distances of all observations to each centroid (with reference to previous step) and assign association degree vector.
3) Assign each observation to the cluster with the closest centroid.
4) Compute the average of the observations in each cluster to obtain c new centroid locations.
5) Repeat steps 2 through 4 until the minimum of the objective function is reached.

3.3.3 Decision making

Through concept clustering, c cluster centroids are critically analyzed as the representatives of the corresponding clusters. The concept alternatives are evaluated according to design criteria. At this stage, designers need to be involved in order to provide their experiences and knowledge for concept evaluation.

However, different design projects may have different priorities for these criteria, and moreover, the influence of different designers on decision-making may be varied.

To represent these concerns, the criteria weight and designer influence are introduced and will be applied on the scoring matrix. Furthermore, the design focus on these three attributes (i.e., function, option, attributes) may be different, thus a weight matrix is assumed and will be applied on the scoring matrix. Finally, a matrix *ES* (*c* x 1), which represents the comprehensive evaluation scores of all the alternatives, can be obtained.

4. Numerical Illustration

In this section, a crowdsourcing design project of future PC design is presented. Four design criteria are assigned: human-centered, novelty, feasibility, and reliability.

4.1 Concept Generation and Collection

The proposed crowdsourcing system will be implemented step by step. The target participants should be PC users. The main features covered by a PC design are shown in Fig. 6. Every feature is denoted as "Feature (degree of freedom, required human input in terms of operation, required human input in terms of attention)."

Membership functions are deployed accordingly for input and output variables. Subsequently, fuzzy rules are generated. Through continuous revisions and improvements, a rule base with a total of 34 fuzzy rules is built.

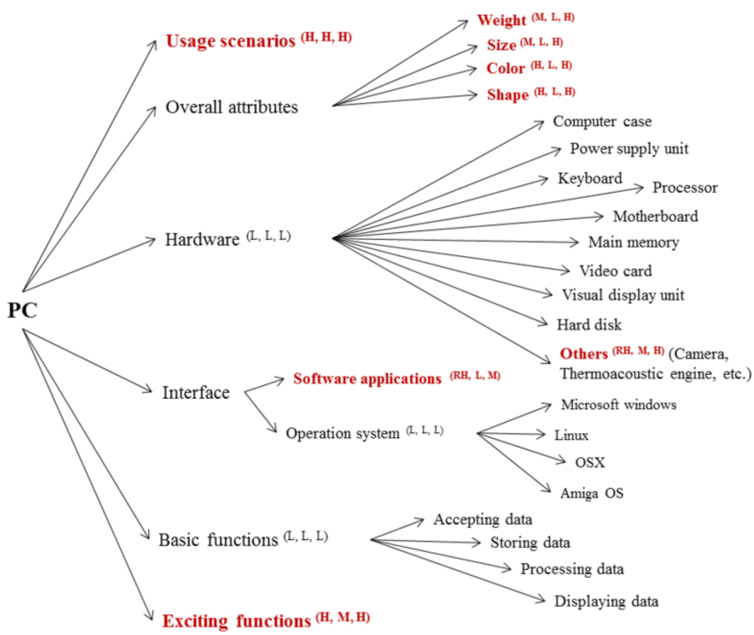

Figure 6. Innovation target analysis (Requirement Level: VL=very low, L=low, RL=rather low, M=medium, RH=rather high, H=high, VH=very high) [7].

However, linguistic inputs should be transformed into a numeric format that can be processed by the fuzzy system. To give a more accurate estimation, a range was used to represent the linguistic variable, and the average value was computed as the crisp input. Therefore, the three dimensions of the inputs are obtained, as shown in Table 1. The output is obtained through the fuzzy system. HITs corresponding generated by the previous step are arranged according to importance. Using the prototype crowdsourcing system, concepts are collected in a given time range.

Table 1. List of Input and Output Data.

Design features		Fuzzy sets		Crisp input	Output
Usage scenario		(H, H, H)	(0.8~1, 0.6~0.8, 0.8~1)	(0.9, 0.7, 0.9)	0.826
Overall attributes	*Weight*	(M, L, H)	(0.43~0.57, 0~0.4, 0.6~0.8)	(0.5, 0.2, 0.7)	0.496
	Size	(M, L, H)	(0.43~0.57, 0~0.4, 0.6~0.8)	(0.5, 0.2, 0.7)	0.496
	Color	(H, L, H)	(0.8~1, 0.4~0.6, 0.6~0.8)	(0.9, 0.5, 0.7)	0.650
	Shape	(H, L, H)	(0.5~0.8, 0.4~0.6, 0.6~0.8)	(0.65, 0.5, 0.7)	0.670
Hardware	*Regular parts*	(L, L, L)	(0~0.3, 0~0.4, 0~0.2)	(0.15, 0.2, 0.1)	0.102
	Others	(RH, M, H)	(0.5~0.8, 0.4~0.6, 0.6~0.8)	(0.65, 0.5, 0.7)	0.670
Interface	*Operation system*	(L, L, L)	(0~0.1, 0~0.4, 0~0.2)	(0.05, 0.2, 0.1)	0.099
	Software application	(RH, L, M)	(0.5~0.8, 0.4~0.6, 0.6~0.8)	(0.65, 0.5, 0.7)	0.670
Functions	*Basic*	(L, L, L)	(0~0.3, 0~0.4, 0~0.4)	(0.15, 0.2, 0.2)	0.111
	Exciting	(H, M, H)	(0.8~1, 0.6~0.8, 0.6~0.8)	(0.9, 0.7, 0.7)	0.801

4.2 Concept Screening and Evaluation

Within a time range, 108 concepts are collected. A pre-processing procedure was deployed to filter out invalid submissions, and 25 qualified concepts are selected for subsequent evaluation.

A data mining process is deployed to extract meaningful textual information from the crowdsourced concepts. A data mining software RapidMiner is applied.

In this case study, the target product is the PC. Accordingly, highly important concerns related to PC design are developed and added to the base frame of the CDH as presented in Fig. 7.

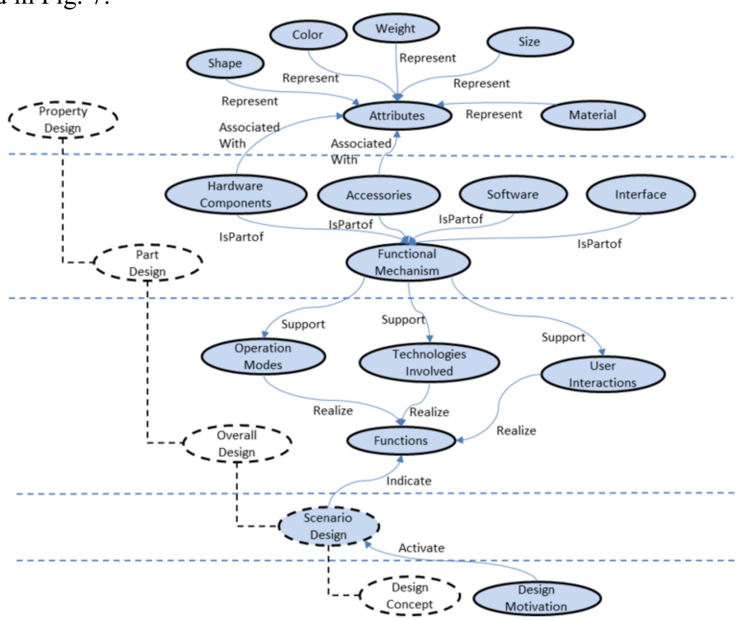

Figure 7. Extended CDH of PC product [8].

Primarily, a process of identifying the proper c value is conducted. To examine the possible influence of c, a series of values are tested on c from 2 to 10. By integrating the concerns of silhouette performance and optimal sum distance, c is finally set at 6. For c = 6, the clustering results are presented in Table 2, and centroid concepts 2, 8, 9, 14, 16, and 25 are identified.

Table 2. Concept Clustering Results.

Cluster	Concepts
Cluster 1	Concept 12; Concept 16
Cluster 2	Concept 1; Concept 3; Concept 4; Concept 9; Concept 13; Concept 18
Cluster 3	Concept 10; Concept 11; Concept 14; Concept 17; Concept 20 ; Concept 24
Cluster 4	Concept 6; Concept 19; Concept 21; Concept 23; Concept 25
Cluster 5	Concept 7; Concept 8; Concept 15; Concept 22
Cluster 6	Concept 2; Concept 5

Subsequently, these centroids are assessed according to the design criteria. To do so, a group of Ph.D. students in industrial design was involved. The weights of each criterion, the influence of different designers, and the priorities of different design levels are assumed to be the same. Through the calculation, a ranking of concept cluster centroids is obtained as shown in Table 3. Based on the ranking, Concept 9 is identified as the best one, thus this cluster may have higher overall design quality and may have the largest possibility to contain the best concept; therefore, it deserves further analysis. The concepts in this cluster are: Concepts 1, 3, 4, 9, 13, and 18. These concepts are identified as promising candidates for excellent concept.

Table 3. Concept Selection Results.

Concept	w/I	ES	R
2	$w_{cri}=[0.25\ \ 0.25\ \ 0.25\ \ 0.25]$	2.25	2
8		4.375	5
9	$I_{des}=[1/8\cdots1/8]_{1\times8}$	2	1
14		4.25	4
16		3.75	3
25	$w_{lay}=[1/3\ \ 1/3\ \ 1/3]$	4.375	6

5. Discussion and Conclusions

This article presents a product conceptualization strategy in crowdsourcing environment. The critical issues associated with crowdsourcing in each essential conceptual design process are studied in detail, and two prototype sub-systems are constructed based on neuro-fuzzy network, domain ontology, and fuzzy clustering. In general, this research makes a contribution to the exploitation of crowdsourcing for supporting product innovation and the exploration of computational intelligence for the management of crowdsourcing data and the handling of conceptual designs.

There are still some limitations of the proposed strategy. Expertise incorporation is unavoidable, which may result in subjective knowledge and personal bias in decision making. Secondly, the number of concepts in numerical illustration is not large enough. Greater participation is expected to further demonstrate the effect of the proposed strategy. A future research is anticipated to deeply study these issues.

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A Case Study of Marketing Research for Academic Spin-Offs: Challenges and Future Prospects

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Abstract. Academic spin-offs usually develop products and services that can be applied for different markets. This peculiarity makes it difficult to carry out marketing research, considering the diversity of segments, channels and segments to be prioritized. This article describes the problem based on the experience of an academic and medical device industry spin-off. Applying an observer-participant research method, the paper describes the development of a marketing research plan for this case and the team´s solutions for the problem. Finally, the paper identifies practices that should be investigated to improve the interface between marketing, technology management and product development.

Keywords. Academic spin-off; market research of spin-off; entrepreneurial university.

Introduction

The knowledge transfer between universities and the market is extremely important factor for development. O'Shea et al. [1] mention the spin-offs generated by universities as important aspects by enabling the development of products through the creation of new industries that will contribute to new jobs and wealth creation.

According to Pavani [2], the spin-off companies are also called start-ups or technological basic seed or university spin-offs. The product or service success of these companies in the market, like in other spin-offs, depends on appropriate marketing study, including identification of potential customers, competitive advantages, strengths, weaknesses, gaps and other known issues.

In the case of academic spin-offs, however, there are uncertainties that make it difficult obtaining a focus and a plan to "attack" the market. Technological innovation means a new know-how, new feature or attribute and this new know-how translates into lots of solutions or classes of potential products that can be targeted to different markets and industries.

The amount of application options of technology and the high number of possible directions is a challenge for this task. This question is not dealt frequently in market research literature. The traditional view is the established companies and mature markets. In this case the first activity is the market segmentation.

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The problem therefore is how to target the academic spin-offs case in which possibilities of products and markets can be so wide? This article investigates the issue through a case study of an academic spin-off the area of medical equipment. It describes the adopted model and discusses the challenges and future prospects.

1. Literature Review

1.1. Support to Academic Spin-Offs

The current focus on academic entrepreneurship based on patents, licenses and creation of spin-offs, needs to be expanded to cover other commercial and noncommercial activity.

There are two complementary roles in the university that promote academic entrepreneurship [3]: the direct academic entrepreneurship, in which world-class research plays an important role in creating innovations that lead to competitive advantage, which can be through the spin- offs creation encompassing academic scientists; and second, the indirect academic entrepreneurship in the education and experience in university research may lead indirectly to entrepreneurial initiatives through corporate spin-offs and start-ups created by students and alumni.

Direct entrepreneurship depends on the creation of knowledge that can support teachers in academic spin-off creation and one way to do it is by creating methodologies and best practices to specifically support such companies.

According to Shane et al. [4], there are several factors that affect the spin-offs creation such as the nature of technology, the industry that the technology will be explored, the university where the technology was developed and the characteristics of the new technology inventors. O'Shea et al. [1] asserts that there are influences of academic individuals involved and environments and university settings.

There are many specific models that describe an academic spin-off setting in stages or steps. Araújo et al. [5] divides the process into four main stages: Stage 1: Ideas and opportunities identification with business potential and its protection; Stage 2: Technical assessment and economic feasibility and idea’s market potential; Stage 3: The company creation and Stage 4: The company's consolidation and economic value.

Market research is a key tool for the first stage. Therefore, the university should be prepared to support start-ups regarding this issue.

1.2. Market Research for Academic Spin-Offs

Market research is the business function that connects the company and customer, through information to support decisions related to the product target, being a functional tool that guides the organization's strategies regarding the consumer behavior and possible segment trends in question and the current scenario.

Market research techniques can be applied to solve these problems such as positioning, branding, consumption potential, customer satisfaction, media and point of sale choice, among others. According to Aaker, Kumar & Day [6], all market research approaches can be classified into one of three general research categories of: Exploratory, Descriptive, and Causal.

However, Faria et al. [7], cites that academic spin-offs have some barriers to bring the technology emerged from research results to the market, either in the form of product or process innovation, which are widely accepted by the market. It appears that this difficulty is natural for academic spin-offs, considering that a good portion of university researchers commence their projects without market approach.

There were no specific articles on market research for companies using this model. This phenomenon can be explained by the authors Oliveira et al. [8] , which identify such companies have great difficulty regarding the marketing plan implementation due to lack of understanding of the concept and its enfoldments by researchers / entrepreneurs, showing themselves extremely involved with the technological innovation process. When we analyze the reality of these companies, we realize that there is pressing irregularities between their marketing skills, which tend to affect competitiveness, assertiveness and market permanence.

Still, there are shortages of probing studies that address the issue of marketing challenges to this business model and there are authors such as Oliveira et al. [8] who claim that companies require different marketing tools:

- Marketing plans are made with short-term view and, in general, without prospects for medium and long term;
- Entrepreneurs find it difficult to create a mission for the company and focus sharply on technological development;
- The entrepreneur's values are confused with the new company's value;
- Difficulties emerge regarding assessment and business weaknesses;
- Entrepreneurs focus on the relationship with the target market entrepreneur;
- Entrepreneurs focus on the technology design process without getting solid information from the market.

Therefore, the lack of implementation reports may be related to the high complexity of new technology; cultural focus to the product / technology, arising from the academic environment; and even the lack of these techniques. Another challenge, not least, is the lack of work plans / implementation specific to these cases. In the following sections describe a specific case research plan for an academic spin-off

2. Methodology

This work was carried out from the monitoring of an academic spin-off created by the Department of Robotics, a branch of the Mechanical Engineering Department of in a Brazilian university. The company chosen for this work implementation was an academic spin-off that emerged through research results developed within the University.

3. Case description

3.1. Project team formation

The team assembled for this project was constituted by five (5) persons, two (2) professors, one (1) business consultant and one (1) professor advisor in the product development segment.

The project carried out by the spin-off research team generated technology, know-how, which has great potential to be incorporated into a given set of products. They managed technical issues and were the stakeholders and decision makers.

The business consultant and expert in product development conducted a support type consulting, offering guidelines for market research as problems emerged.

3.2. Project opening meeting and PC elaboration

A first meeting occurred to clarify the technology and its characteristics to those involved in the project. It was given the authorization for the Project Charter and the data gathering deadline was set.

As a result, one of the team members prepared a PC - Project Charter - from a document template as Appendix 1 - TAP.

The main concern was the identification of deliverables. They were defined as follows: 1) Business Model; 2) Project Deadline; 3) Members activities; and 4) The next team meeting date.

3.3. Meetings and in Loco Technology Observation

The Market Research Theory proposes a set of information sources, suggesting the distinction between secondary and primary sources. In this sense, the marketing researcher should start its work seeking to exhaust the secondary sources usually being a cheaper thesis, and then go for more accurate surveys, observations, etc., their primary sources.

Thus, it was possible to see that professors and researchers in academic environment establishing contacts with clients and companies throughout technology development. In this activity they accumulate a quantity of information. An important decision of the business consultant was the use of observation methods, at first, focused on the research team.

The business consultant visited the lab where the technology was developed, and in addition to gather information related to the process, the ongoing activities progress and the functions organization was observed as well. This was important in many aspects, since:

a) Allowed greater technology knowledge, laboratory operation and contact with other developing technologies;
b) the research team activities have been described;
c) There was an approximation of the business reality.
d) There was a prototype physical contact and testing
e) partnerships and agreements signed for prototype testing between universities have been reported;
f) A high degree contact with a partner in a company born from an academic *spin-off* in the United States that develops similar technology was mentioned;
g) There was a greater commitment concerning the developer team;
h) One of the professors in the development team entrepreneurial vision was noticed.

It was possible to identify some internal communication gaps, the high focus on technology development, the average market knowledge t and the absence of time control delivery. Arguably this step brought more analytical data and the production process understanding, but there was a need for exploring information related to companies developing similar technologies, which is reported in the following topic.

3.4. Market information search

The second stage was characterized by the search for additional information. So one of the limitations found consisted of the time and investment needed to carry out extensive market and segmentation research. The given solution was to use simple and synthetic data sources. In this case, we used the DATAVIVA [9] database to search for information and open data.

According to the website, DATAVIVA is a tool created through the Strategic Priorities Office of Minas Gerais government and an international consultancy, with the initial target to assist the government's economic development policy of Minas Gerais state. In result, platform potential as Big Data tool was noticed: the platform has data from all over the country, which helps not only Minas Gerais state. The databases are composed of data provided by the Labor and Employment (MTE) and by Development, Industry and Foreign Trade (MDIC) Ministries. DATAVIVA presents the export data on 1,256 products of Foreign Trade Secretary and the 865 occupations among 427 economic activities, from the Annual Social Information Report. Other statistics within this platform are the School Census and Higher School Census database which include gathering information from primary to higher education and United Nations Commodity Trade Statistics Database (UN Comtrade) containing detailed statistics on imports and exports reported by the statistical authorities of nearly 200 countries.

The information, though rich, its content was general and depended on a market segment or group choice in order to be more accurate.

3.5. Target market choice

The initial survey conducted in the previous step, as well as data obtained from observation, indicated the existence of a significant number of products to be offered to a range of potential consumers.

This aspect, initially positive, generates, however, a focus problem: it is not possible to accurately analyze all these markets and segments, for all product possibilities.

The given solution was a creation of general and alternative business models dynamic. The idea was to probe several options that would allow the team to prioritize a smaller set of markets and segments to explore.

The meeting was prepared with the assistance of graduate students in Industrial Engineering. They were driven to propose different solutions and generate new ideas and capabilities that could be presented to the project team. With these researchers assistance, four scenarios were generated and described in the Canvas Business models type that served as a starting point for the project team work

Initially there was a presentation of an executive summary containing the data collected performed by the business consultant to assist the project understanding. The executive summary was constituted of market data: context, target group and the final consumer; technology description; possible products to be developed using the same technology; similar and future competing technologies presentation; presumable distribution channels.

So, four BMG models - Business Model Canvas were provided to fulfill the criteria and gather all the information that encompassed every possible product. The choice of this method can be justified by the use of visual features such as picture and adhesive stickers contributing to the participation of members and autonomy during the activity.

Sebrae's booklet on Canvas [10] presented as a tool created by Alex Osterwalder and Yves Pigneur through trials and studies. It's called Business Model, where can be displayed the description of the business and its component parts, so that the idea is understood by people who see it in the same way who developed it. It consists of nine sections: value proposition, customer relationships, customer segment channel, major partnerships, key activities, key resources, cost structures and revenue streams.

In this process, there was brainstorming considering all the students' ideas and opinions of unrestricted possibilities in completing the Business Models. Upon completion of this dynamic another meeting was carried out with the project members for the presentation concerning the business models analysis results and settles the proposals.

Developers analyzed the business models and selected two of them that met in focus and group perspective. This process of funneling ideas and proposals is shown in the figure below.

3.6. Market research conclusion

The business consultant conducted a new stage for further research on the two business models specific markets. The form chosen to complement the information was interviews with distributors. In this case, a company interested in knowing the technology has been identified. A meeting for experiences exchange between researchers and the commercial representative was arranged. Besides knowing and testing the prototype, the commercial representative reported factors and important information for business plan detailing as:

a) Segment peculiarity / entry barriers (standardizations, legislation and taxation);
b) Technology recipiency;
c) Segment trends;
d) Possible technology versions to reach other consumers;
e) Guidance on critical issues concerning the technology insertion context;
f) The brand significance;
g) Import and export trade markets;
h) Probing the competition actions;
i) Possible partnerships.

The interview did not change significantly the developers' focus, but contributed positively to guidance and clarification of market positioning doubts, entry barriers, norms and segment trends. Market research was oriented in order to complete the business plan prior to the deadline given by the project team.

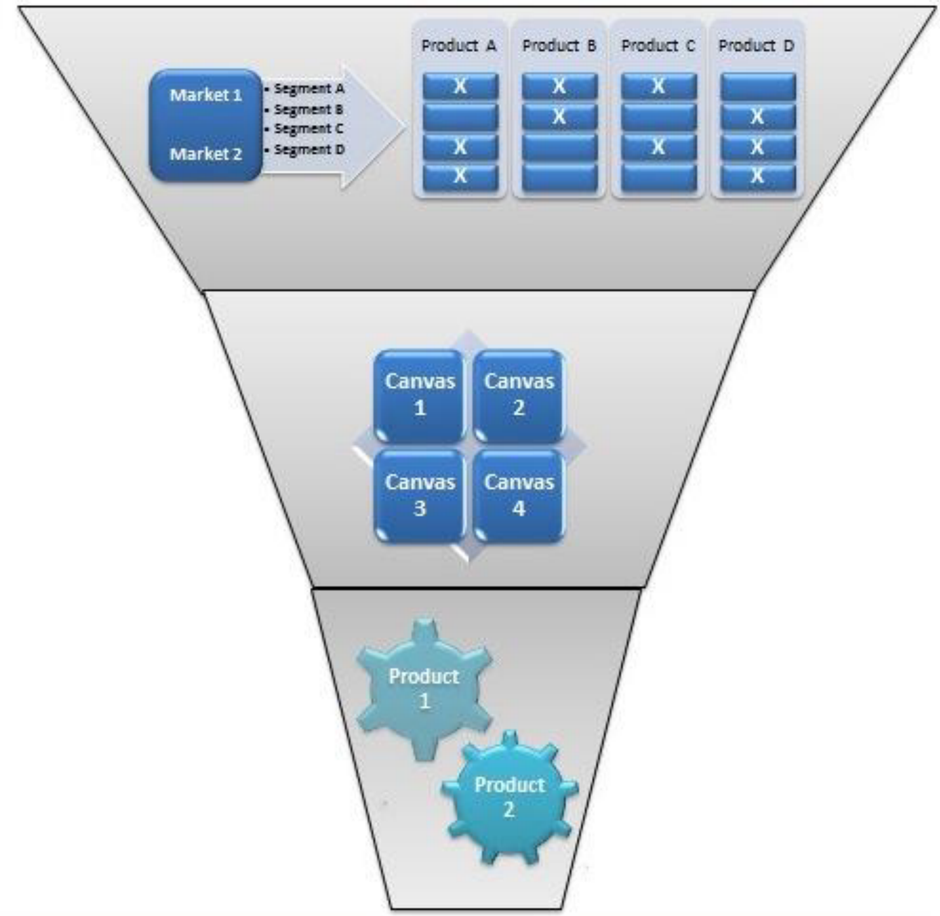

Figure1. Ideas development funnel and business model.

3.7. Future academic spinoff market research applications

In order to gather all the activities involved in this study and to guide possible spin-offs in the market research development, follows a sequence of steps that can facilitate implementation.

Phase 1: Design team selection for market research. In this first phase it is essential to choose those responsible for drawing up the search. Typically, non-academic spin-offs undermine the market studies for the target segment knowledge. Within these business models there is a strong concern with the product and the development team, lacking of management skills. With this initial difficulty, the spin-off should select members who have skills and management expertise to direct the market research and even be appointed a project manager. It is very important the experts help, related area researchers and technological entrepreneurship support agencies.

Phase 2: Meeting to align the design and integration team. If the spin-off insert external support agents to market study, their integration to project goal alignment that will be developed is needed and the team members and stakeholders expectations understood. It is suggested in this stage a Project Opening Statement elaboration containing the activities descriptions and approval of all members before starting the market research project. If necessary, considering the project safety, this step could also create a confidentiality term for all the participants. Academic spin-offs can be oriented by innovation agencies regarding the use of confidentiality agreements within the university.

Phase 3: Knowing the technology or product to be developed. This step is extremely important to present the product or the idea of it to all the external agents or experts who will conduct the market research. If the product or prototype has already been developed at this stage you can insert a target customer to test the functionality or perform tests with costumers' focal groups. The project manager along with the specialist should measure and evaluate customer needs and register, forwarding the possible changes to the product.

Phase 4: Knowing the customer and target market. Search on the customer and the market that the new product will be inserted is a survival factor for the companies. You need to map all possible customers with their specific needs and through these results, decide which types of customers are part of the company's strategy and its stakeholders. Big Data and specific research tools will provide useful information for understanding the public. After prospecting possible costumers in a generalist way you need to select the target. At this stage, the use of business model (Canvas) can provide important general guidelines to be considered in this market decision. In case of similar products scenario it is necessary to identify its market position and its competitive differentials.

Phase 5: Wrapping up the market research and creating a business plan. After the conclusion of the phase above, a detailed study concerning production capacity, distribution channels, resources and initial investments required for the company's inception is essential. It is important to be aware of the entry barriers, specific legislation, market trends and economic fluctuations. A complete business plan and all the data resulting from the above phases can be a crucial tool for the beginning company, the inclusion of new investors and the possibility of initial funding to encourage entrepreneurship.

4. Conclusion

The work fulfilled its objective regarding to the exclusivity of the model adopted for market research. The market research theory is emphatic about the importance of understanding the needs, perceptions and customer emotion, however, this case shows that the observation of the development team, especially those called to assist the Marketing Planning is fundamentally important since they contributed significantly to the project outcome as it allowed better research adjustments. This is a hypothesis for future research.

A practice that was proved interesting was the web database use that synthesizes market information, such as DATAVIVA, facilitating the search for data and optimizing time and project resources.

The case suggests that one of the research markets challenges in academic spin-offs is the great flexibility in terms of market performance. Unlike an established company, which already has a target market, this group of individuals would have to create their own distribution channels. This means they can opt for different segments and product types. The challenge is to find methods of market identification and prioritization, even considering the limited information. The goal was achieved with the use of BMG tool - Business Model Canvas, or simply, Canvas, but the team's perception is that a set of enhanced techniques can be developed and applied.

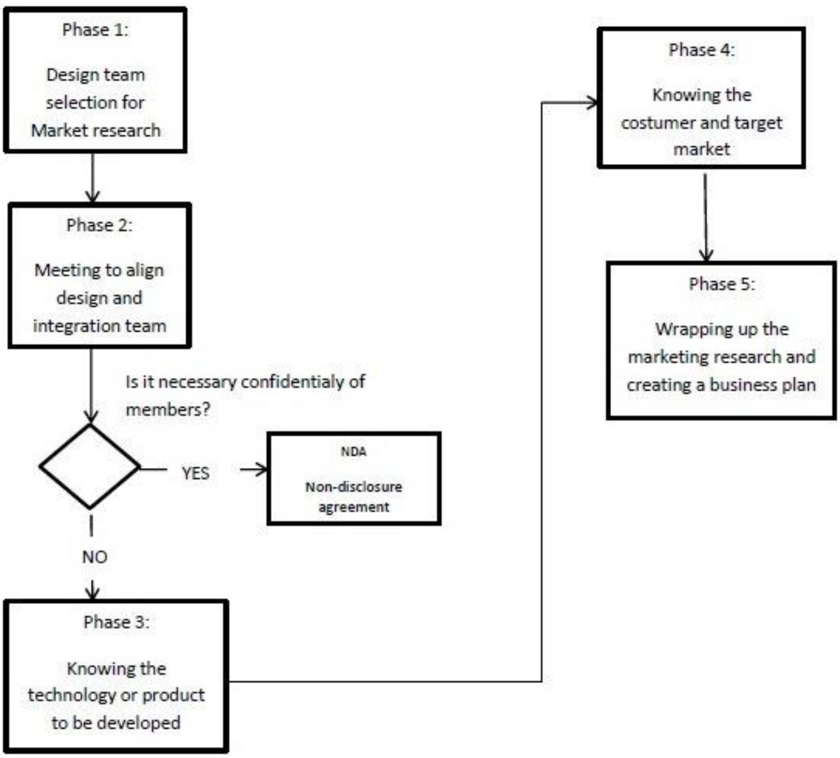

Figure 2. Flowchart market research process for a academic spin-off.

The graduate student's participation that was not considered as a part of the initial project was a positive factor in the assembly of possible marketing scenarios, both project management and product development researches, and its collaborations have increased the development of alternative and supplemented with data on the project context interpretation.

The information exchange between commercial representative and the researchers' team in this particular study case brought the involvement of researchers into market research. This shows that in the project integration, there is no parallel development of the steps, including developers throughout the stages, facilitating the decision making of the project steps and guiding possible changes in the course of it.

To the future research references, it would be possible to work with scripts for teams of developers observation; studies and proposals of *Data Mining* and *Big Data* tools for specialized analysis in technological innovation markets; techniques proposed for prioritizing markets for academic *spin-offs*; and also with the use of visual tools such as *Canvas* and *Design Thinking* in development stage ideas to support decision making.

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Part 17

Requirements Engineering

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How to Challenge Fluctuating Requirements – Results from Three Companies

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Abstract. This paper presents the results from a research project conducted by the research group Computer Supported Engineering Design (CSED) in Jonkoping University in Sweden. The project has the aim of increasing companies' ability to respond to fluctuating requirements when developing new products and product variants. The companies participating in the project represents automotive, aerospace and production equipment industries. Three different cases of applications have been developed and implemented in the companies. Product models ranging from product to knowledge centered for use in the company's product and technology platforms have been demonstrated and evaluated though interviews with professionals at the companies. To summarize, the results shows that the companies' abilities to respond to fluctuating requirements have increased albeit concerns have been raised on the maintenance of knowledge in the implementations.

Keywords. Product Model, Platform, Requirements

Introduction

This paper summarizes the results from a research project spanning between the years 2014 – 2017 and attempts to generalize the results from cases of applications made at the participating companies within the project so far. The title of the project is Challenge Fluctuating and Conflicting Requirement by Set-Based Engineering (ChaSE). It involves four senior researches and four PhD students and around 12 representatives from four different companies. Three of the companies are first and second tier suppliers in automotive and aerospace and the forth supplier is in production equipment. The fourth company supplies tailored production lines consisting of standard equipment such as CNC machines and robots that are selected and arranged to an efficient and robust production line. The special parts needed to tie together the machines to a complete production line are designed and built.

The companies are business to business (B2B) suppliers except one of the two automotive suppliers which in part is an original equipment manufacturer (OEM). The companies are further described in [1].

The aim of the ChaSE project is finding how companies can increase their ability to quickly respond to fluctuating and contradicting requirements when designing products. This was identified as an important competitive factor when setting up the project.

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The companies experience fluctuating and contradicting requirements due to their business model. The suppliers are expected to quickly answer questions from the customers about what consequences proposed changes in the requirements specification will have for the product being developed. Further, the OEM:s has to orchestrate a multitude of sub-suppliers in their aero engine or automotive development projects.

At the starting point of the project, it was assumed that Set-based Concurrent Engineering (SBCE) will support this ability in that a set of different design suggestion is more likely to meet fluctuating and conflicting requirements than a single one.

In the project it was also assumed that the use of product and technology platforms can contribute to increasing the capability of responding to changing requirements. In the platforms (Figure 1), the knowledge on products and processes are represented as models. From these models, new designs and design variants can be derived or alternatively the know-how on how to design them can be retrieved. It is the companies' common body of knowledge that is represented in the platforms with a varying degree of formalization [1].

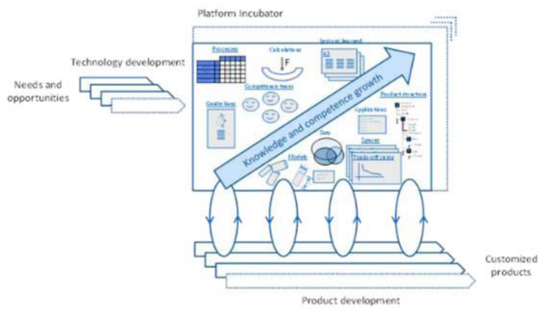

Figure 1. Conceptual platform in ChaSE.

Starting from the left, there is a technology development for introduction into the platform going on, represented as several parallel processes. This is governed by the market needs and opportunities that emerges. When sufficiently ready, these technologies are formalized into models and amended to the platform. This is gradually extending the platform, and a continuous refinement of the models are being made, hence the name incubator.

From the platform, solutions are derived and used in product development projects with the aim of designing a specific product or variant as seen at the bottom of the figure.

The ChaSE project is concerned with the format of these models, aiming to prescribe how they should be constituted to increase the ability to handle the fluctuating and contradictive requirements. The project also aims to prescribe how they should be operated in the set-based environment to increase knowledge reuse and support a streamlined development process with controlled variation.

1. Literature review

As mentioned, the basic assumptions of the ChaSE project involve SBCE and product platforms. In this section the state of art of the terms is accounted for and the interaction between them is elaborated.

The set-based approach is characterized by using a larger set of design suggestions rather than striving to freeze the design specification as quickly as possible. This leads to a more thorough exploration of the design space and a knowledge build up. More resources is spent in SBCE than in traditional PD [2].

SBCE also affect how the requirements are handled. Rather than specifying a point, a range is specified. As the design work progresses, the ranges are gradually narrowed down to arrive at a point at the end of the project. This means that the dependencies in the design can be resolved or be made less strict. Thus, design work on several sub systems and components can begin at the same time. This have had positive effects in industry as observed by [3].

1.1. Platforms used in engineering design

There is no precise definition of a product platform. The existing definitions ranges from a platform consisting of components and modules [4], a group of related products [5], a technology applied to several products [6], to a platform consisting of assets such as knowledge and relationships [7]. This is also reflected among sub suppliers, as shown in [1] where the company platform description is categorized on four levels of abstraction and compared to their customization strategy. A risk emphasized in literature is the trade-off between commonality and distinctiveness [7]. Another trade-off is the one between increased development efforts for the initial platform and the uncertainty whether the right platform is chosen in order to develop a sufficient number of variants to gain back the extra expenses [8]. Platforms are generally described to be of one of either two kinds: Module based (discrete) or scale based (parametric) [9]. Source [10] suggests that one deliverable from TD can be a technology platform, this is further investigated by [11]. In [12] the author questions if companies have a choice regarding implementing a platform or not since platforms can exist on several levels. All companies pursuing product development has a product platform to some extent.

In the cases of the ChaSE project, the level of readiness of the product before the agreement with the customer is made, varies between the cases. The point where the adaptation of the product to a specific customer is made is referred to as the costumer order decoupling point [13]. Source [14] divides specification processes into four levels in the following way: (1) Engineer-to-order, (2) Modify-to-order, (3) Configure-to-order and (4) Select variant. In (4) everything is prepared prior to the customer's order. The other extreme is (1) (ETO) where very little is prepared. In this case the platform consists of product knowledge such as applicable norms and regulations. (2) is represented by a generic product that is adapted to the specific case and (4) is combining ready modules without altering the design.

2. The research method

Along the project, interviews and workshops with the companies to identify which factors have an influence on their ability to respond to fluctuating and contradictive requirements have been conducted. The work has followed the DRM (Design Research Methodology [15]. In DRM it is emphasized that after an initial research clarification, success criteria (SC) and enablers (EN) should be formulated early in the project.

In the ChaSE project, the companies were gathered at several workshops where they formulated the SC:s and prioritized among them. "Reuse of knowledge" emerged as the most important followed by "Time to respond to quotation". At the third level of importance was "Short start-up time", "Time to build and maintain infrastructure", "Assure fulfillment of requirements", "Number of iterations" and "Keep project time". Finally "Support the designer" and "Re-use components" were rated as the fourth most important.

In each of the companies, the SC:s are supported by EN:s. The EN:s were also identified through interviews. Work started to set-up pilot systems at three of the companies to implement these EN:s.

The business model of the fourth company (production equipment) is different from the three others. In this company, the requirements can be definitively set at the beginning of the project and therefore the company is not expected to be responsive for enquiries on changes of the requirements to the same extent as the other three companies.

After implementing the pilot systems, the impact on the SC:s were estimated by interviews with professionals at the companies.

3. Results

In this section, the three company cases are described together with the results of the interviews.

3.1. The Aerospace company

The aerospace company is a very large organization with 44 000 employees. The studied part of the company has 2000 employees.

In new generations of air-craft engines, the demands on weight, thrust, fuel consumption, service life, noise level are increasing. Further, the number of aircraft manufactured are rising, placing demands on the efficient manufacturing of the products. Consequently, the company needs an active and innovative technology development. The company make extensive analyses in the early conceptual stages using an environment consisting of several commercial and in-house software that has been integrated. This is in this paper called the CAE environment. The CAE environment combines parametric CAD with e.g. FEA, CFD and rule-based evaluation. In early phases of development conceptual designs are proposed. These are evaluated in the CAE environment. The motivation is building knowledge and understanding the trade-offs in the conceptual design. The evaluation is done in an automated process so that hundreds of different geometrical variants of the concept are evaluated for structural strength, aerodynamics, lifetime and more. Through these experiments, knowledge is gained on how the geometrical parameters (lengths, angles, number of vanes etc.) affect the performance of the engine.

This enables the company to get an overview of what sets of requirements that can be met, so that they can assist their customers in formulating the requirement specification. It also makes the company very responsive should the customer request to change anything in the specification. Questions of the type “what if..” can readily be answered.

In the case studied, the capability of the CAE environment has been extended to also include manufacturability evaluation applied to robotic welding. For each variant it is evaluated if:

- It is possible to access to weld and inspect the welds.
- The material thickness is within the permissible range of the weld process.
- The variation in thickness is permissible for the weld process
- The material and the material combinations can be welded
- The curvature of the weld is not too small for the weld process

The Figure 2 (right) shows a fictitious static turbine component. It consists of a cast hub and several sheet metal parts that are welded together to 10 sub-assemblies that in turn are finally welded together to a complete component. This is done in a series of robot welding operations, requiring fixtures to be made in each welding sequence.

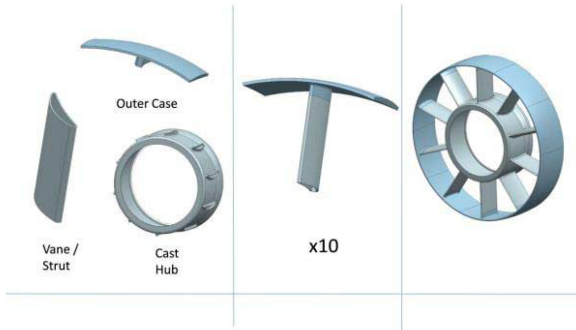

Figure 2. Welded turbine part.

The company employ a variety of different robotic weld methods: TIG, Laser, Electron Beam (EB) and Plasma. For each of these weld methods different ranges to the above items apply. In the evaluation it is checked which of the weld methods (if any) that comply with all the constraints. This results in a list of permissible welds methods for each group of welds. To make a final selection of weld method, a prioritization list for the intended manufacturing site is employed. Among the possible weld methods, the most preferred one is selected. After establishing weld methods, process plans are automatically derived so that a cost estimate and a sustainability evaluation can be made.

The estimated cost and sustainability values are reviewed together with the results of the other analysis allowing a decision to be taken on how to set the geometrical parameters of the concept to comply with the requirements. This is described more in detail in source [16].

The company describes different platforms i.e. manufacturing platform, analysis platform and so on. It consists of a number of well described and validated methods on how to perform the activities needed. The platform also encompasses in–house developed software for automating the described activities.

To evaluate the weld part of the CAE environment, one production and one design engineer with long experience in the company where interviewed separately.

Their answers were consistent that the company has a need of predicting the manufacturability in early stages. The proposed manufacturing module seem promising, but the results from in presented as manufacturability index was difficult to interpret. Instead key indicators like the number of welds that are expected to be difficult to inspect or the minimum weld-radii should be presented. Further, more runs on actual components were needed.

3.2. The first automotive company

The company employ 10 000 in total and about 600 in the studied organization. It supplies equipment for enhancing driver safety and comfort such as active head restraints and seat heaters, massage and ventilation in car-seats. The focus of the case at this company is the quotation process. There are frequently requests for quotations (RFQ) sent by car manufactures. In some cases, an off-shelf technical solution can be adapted to the car seat design proposed by the car manufacturer. This is, however, rarely possible which means that some design work has to be done to respond with any precision to the quotation. Further, the cost for preparing the quotation is in most cases not covered by the car manufacturer. In addition, the likelihood of actually getting the contract is low for some quotations. The company is in principle willing to customize or redesign each part of the system if required in order not to lose business. It is however desirable to reuse as much as possible from previous designs and previously created knowledge. Due to the high level of customization that is offered, the speed and accuracy in the quotation process is an issue. Speed is important to quickly return an offer to the customer whereas accuracy is of importance to charge the right price. It is therefore vital to reuse as much of already developed assets as possible which puts high demand on finding the needed information and be able to judge the applicability of it.

In order to respond to the need of efficiently conducting customization, a platform approach was developed, adapted and to some extent realized in the company. Due to the relatively low possibility of component and sub system reuse the introduced platform approach, called Design Platform (DP), aim at reuse on a higher level of abstrac-tion. In the DP approach, the platform is defined by:

- Descriptions of product instances and their interrelation to a generic description, which means that the platform evolves as the instances are successively created.
- Descriptions of the building blocks of the designs and design process and the both generic and specific descriptions of those.

The approach is object oriented and starts by the identification of generic product items which is the main class. The generic product item can many times be in the form of a generic product structure but also in the form of a generic module or component. Design Elements (DE), which are discretized blocks of knowledge descriptions, can then be associated with the items. The DEs are inspired by the ICARE forms in [17] and consist of entity, activity, rule and constraint.

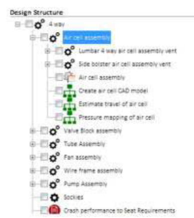

Figure 3. Part of the GUI of Design Platform Manager.

In order to realize some parts of the DP approach, an application was developed called the Design Platform Manager (DPM) (Figure 3).

The application enables the user to model generic product items, couple DE:s to the different levels in the generic product item structure and instantiation. The application is based on spreadsheets, XML and a user interface that allows the user to browse through generic product items, instances and DEs. The DEs are modelled using standard templates that include properties and characteristics that are important to judge validity and applicability of the DE in the specific context. When a quotation arrives the system is used to get a first view on what exists and what doesn't. The Figure 3 shows a 4-way seat comfort being designed. In addition to the available parts and assemblies, the tree structure also contains a number of activities as e.g. " create air cell CAD model" and "estimate travel of air cell" need to be made before the design can be finalized.

At the company a Request for Quotation (RFQ) usually concerns several specific types of systems with different levels of functionality. The corresponding generic product item can then be browsed in order to find DEs that fulfills the customer re-quirements. For some levels in the structure there will be associations with finished designs of components and subsystems (Entities) that fulfills the customer requirements. For other levels there will be no associations to finished designs, this is specifically common for the components and systems that interfaces the customer product and where subjective requirements are common. In these cases there might be associations to other kinds of descriptions describing e.g. a task, parametric CAD model or calculation spread sheet (Activities, Rules or Constraints) that aids in the designing of the desired component or sub system. The DEs that are judged to comply with the customer requirements are picked to be included in the instance.

Also this system has been evaluated through individual interviews with three employees with long experience in the company: One engineering manager, one design manager and one quality engineer. There was consistency in their answers. The system will contribute to decreasing the time spent on answering quotations as well as ensuring that all requirements are fulfilled. It will also contribute to a better re-use of components and product and process knowledge by providing an overview of the components and the knowledge. The system will require an effort in keeping up to date as identified at the interviews.

3.3. The second automotive company

The second automotive company supply solutions for the active, sporty consumer to bring equipment such as bicycles, kayaks and skies, allowing them to be transported on motor cars. The organization studied employ around 300 people. The company works both directly towards the consumers with aftermarket products as well as towards the car manufactures as an original equipment supplier.

The case is concerned with the aftermarket products. As new car models emerge, the solutions are adapted to fit the new model. One bottle neck when in doing these adaptations is to predict the behavior in a crash. Regulations stipulate that the roof rack must stay on the car when subjected to a specified acceleration. The simulations needed to predict if a proposed design will pass the crash regulations are complex, involving not only the product itself, but also the car roof. To set up the simulations require expert work. However, augmentation software has been developed within the project and has been introduced in the company's CAD / FEA systems, showing that it is possible to partially automate the process. This shortens the time to make the evaluation. It is possible for the design engineers to operate the system. The system is designed for a special type of roof-rack where a basic design is adapted to various car models. This is done by customizing a pad and a bracket interfacing the roof. The complexity of the simulations which includes large deformations makes it necessary to make structured meshes rather than just tetrahedron filling, adding to the difficulty. The system identifies the different components by their names in the CAD models. It then finds lower level elements in them so that the structured meshes can be created in the FEA system using extruding, revolving or sweeping. An FEA model can be solved on a powerful computer cluster in a few hours, resulting in a prediction if the proposed design will pass the regulations for road safety of not. This makes it possible to enlarge the set of designs under consideration, adding to the ability to quickly respond to requests for changed requirements in other aspects than crash regulations.

The evaluation interview involved five professionals at the company: Chief engineer, simulations expert, project leader, director of product development and a technical manager.

All participants saw a potential use of the system at the company. Positive comments with respect to the potential time and safety improvements were given. One went so far as to say it was a requirement to be able to meet the deadlines in the future.

However, skepticism was emphasized on the lack of detailed information regarding the implementation and maintenance required. As well as risks related to losing control by putting too much trust in the system.

Most participants saw the responsibilities for the CAD models to fully lie with the designers themselves, FE-models with the simulation engineers and the connecting subsystem with the researchers.

Potential drawbacks given were; the amount of time required to formalize the methods to automation standards, loss of control with respect to quality of results, maintenance and development might require large amount of time.

Further work suggestions involved starting to run the simulations because that is when issues appear, improve user-friendliness when defining the FE-models and provide proper instructions, have periodic follow ups between researchers and company staff and finally a warning not to underestimate the complexity.

4. Discussion

The three systems presented are in roughly the same state of development where the wanted system characteristics have been defined and demonstrated. The systems' place in the organizational work flow have been pointed out. The Table 1 below summarizes the company cases in terms of the type of platform, how it supports the ability to respond to fluctuating requirements, and the considerations for maintaining the platforms over time.

Table 1. Summary.

Company	Platform type	Response to fluctuating requirements	Maintaining the platform
Aerospace	Automated explorative studies.	Explorative studies in conceptual stage provide overview of the relation between design and performance parameters.	Uncertainty on future concepts. Useful for accessing incremental improvements of existing designs.
1st Automotive	Augmented product structure.	Provide overview of the effort required to meet a proposed set of requirements.	Support the stepwise introduction of new technology. Does not require complete automation.
2nd Automotive	Automated verification process.	Shortened time to verify designs compliance with safety regulations.	Need to monitor changes in road traffic regulations. Single base concept.

Since the systems have not so far been operated on actual design problems, the interviews have mainly been concerned with demonstrating and evaluating the proposed working principle and the systems role in the organizations. There is consensus that the companies' ability to respond to fluctuating and conflicting requirements will increase. The reason is that the time to evaluate a design suggestion will be shortened, making it possible to work with an enlarged set of design suggestions. Further the variations in doing the evaluations are expected to decrease in that the process becomes more formalized. This is expected to decrease the risk of overlooking any of the requirements.

What has been identified as an obstacle through the interviews is how the systems will be kept up to date. Should the information be obsolete, it can be assumed that the organizations confidence in the systems will soon be diminished. The intent is that the professionals in the companies will keep the systems up to date. However, this require high transparency and maintainability of the systems. Resources needs to be allocated for system maintenance. The staff must be given time to learn the systems and to operate them to be able to assess the amount of resources needed.

The second automotive case has the most well defined scope. It is one type of product where only few adaptations are made. It will presumably be easiest of the cases to implement in the organization. The system will need to be extensively revised when the basic concept is altered.

The situation at the aerospace company is less well defined since it is more of an ETO company than the automotive companies. It lacks the generic product structures. It is not known what types of engine concepts will emerge in the future. In the intake parts of aero engines carbon has begun to replace titanium. At the exhaust side more ceramics have started to be used instead of nickel alloys. This can make welding as a joining method less important. The system will then have to be extensively revised to accommodate new manufacturing methods which have different critical issues than todays. However, the time between the emergence new generations of products is generally longer than in automotive. The lifespan aerospace products are longer, 40 years or so. Here the aerospace platform can serve for a long time when investigating the impact of suggested incremental improvements on existing engines.

The first automotive case can be expected to be long lived. The business model is based on that there is a generic product structure that can be adapted at request for a new seat. New technologies for seat design will likely emerge as more weight will have to be saved in motorcars. This will require new types of components in the product structure, but the product based nature of the problem will remain.

The case of the second automotive company has the most well defined limitations. It is a specific, repetitive task that is well suited for automation. Since the problem is well defined, the risk of implementing it in the actual product development process can be expected to be low.

5. Conclusion

Three company cases have been implemented with the aim of increasing the companies' ability respond to fluctuating requirements using set-based concurrent engineering. The DRM has been followed identifying the SC:s and EN:s by interviews and workshops. It can be concluded that the companies need to increase their ability and that there is a common understanding that and the systems presented will achieve that. The maintenance of the systems that will be done by professionals at the companies is a critical issue for success of these implementations in the long run.

The ChaSE project is in a state where the EN:s i.e. the systems and their desired characteristics have been defined and demonstrated. Before it is possible to collect any data on to what extent they support the SC:s, the systems needs to be tried out on actual design problems. It is intension is that the researchers will show the professionals how to operate the systems both on former and new design problems. A more thorough evaluation will then take place, planned in the fall of 2016. This evaluation will also be based on interviews, however more detailed and with actual data from development projects available. It is thought that it then will be possible to show qualitative data on to what extent each of the SC:s are supported by the EN:s, possibly in a matrix format like QFD, house of quality.

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Driving Product Design and Requirements Management with SysML

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Abstract. The Product Development Process (PDP) multidisciplinary aspect, under Concurrent Engineering (CE) principles, leads to overwhelming complexity, where several systems, methods and tools are used in a process with intensive information flow. Nonetheless, the absence of a common language for describing information components, regarding product, process, design and business, give rise to multiple interpretations, hindering full understanding and therefore produces rework and quality issues. This scenario highlights the need for ways to make the availability of product requirement information more dynamic and scope-sensitive (i.e. different levels of abstraction) along the PDP stages. In this context, Model-based System Engineering (MbSE) and supporting system-modeling languages such as SysML propose a product representation structure, through a unique and timeless model, which potentially drives the whole product lifecycle, as the single and ubiquitous information source to stakeholders. In this sense, the goal of this work is to propose a system model that provides reliable product representation, able to support product requirement definition tasks and their use along the PDP, allowing significant gains in productivity and reduction of non-conformities. The methodology adopted in this work follows the principles of DSR (Design Science Research), considering a real scenario inserted in a multinational enterprise context, in the agriculture-applied machinery sector. The model proposed is expected to assist the generation and usage of product information at various abstraction levels, by all stakeholders during the PDP, therefore reducing rework and enhancing design quality.

Keywords. Model-based Systems Engineering, System Modeling Language, Requirements Management, Product Development Process.

Introduction

The Product Development Process (PDP) is characterized by complex information flow. Information are shared across different languages (e.g. 3D models; spreadsheets; texts; mathematical formulas, videos, images), without a common language, giving rise to multiple interpretations on the whole product [1]. This information discontinuity, mainly the difficulty in interpreting and manage requirements, generates the need for product changes, requiring extra efforts and costs [2]. Several computational tools have been developed to work with Product Lifecycle Management (PLM) for requirements management (e.g. Polarion, DOORS). However, in practice these tools are applied in a

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standalone way, therefore not ensuring integration along the product lifecycle and potentially causing misalignment between requirements and product features [3]. Thus, this scenario demands models that help designers of several different technical skills to access the required information easily, quickly and reliably, allowing traceability [4].

Model-based Systems Engineering approach (MbSE) has been proposed as an alternative to information flow representation to complex products. This approach aims to allow the maintenance of complex engineering systems [5]. In this context, System Modeling Language (SysML) has been highlighted. SysML has been applied in [6]various industries for the purpose of modeling requirements, describing physical connectivity and modeling the structure of organizations [7]. In this sense the research questions addressed in this work are:

- Q1. Could a SysML model allow better correlations between different requirements and product components?
- Q2. Could a SysML model allow unique understanding of the requirements among stakeholders?
- Q3. Could a SysML model allow better requirements management and traceability?

The goal of this work is to propose a model that can support requirements management of complex products across the PDP, being the unique stakeholders' information source.

The present article is organized as follows: Section 1 of this paper presents a brief literature review on SysML, applied to requirement management in the PDP, as well as a theoretical overview on the types of information handled along the PDP, fundamentals of SysML and requirement management. Sections 2 and 3 describe the methodological aspects of the present research and the proposed model. Sections 4, 5 and 6 bring preliminary results of the study, a short discussion on the findings and the conclusions.

1. Conceptual Background

This section describes the basics concepts used for developing the proposed model and a brief literature review on the main applications of SysML in the context of PDP and Requirements Management (RM).

1.1. State of art

Some authors have proposed the use of SysML and UML to optimize development and requirements tracking throughout the PDP [8]. Very few studies focus on the standardization of SysML modeling inputs for the beginning of the PDP, and how this information can be viewed and tracked by stakeholders from different disciplines and different abstraction levels towards the PDP. [9] propose the use of a framework called RSL (Requirements Specification Language) based on SysML to formalize the requirements in embedded systems development applied to automotive systems. However, there is still a gap in the literature, focusing on how standardized information are converted into SysML diagrams at early stages of the PDP, and its correlation with other system components.

1.2. Model-based Systems Engineering.

The MbSE approach allows to develop system and process models, through specifics languages, as well as the description and application of relationships between components of a system through transformation models [10]. In the PDP context, MbSE allows semantic consistency between various knowledge domains through formal languages, machine-readable statements, thus enabling interoperability between different tools (e.g. CAD, CAE, ECAD, discrete simulations) as shown in Figure 1 [11]. The scientific literature suggests two main languages related to MbSE applications, which are the United Modeling Language (UML) and SysML.

1.3. Unified Modeling Language

UML is widely used in industry as a standard for object modeling [12]. It allows graphical representations of products by means of several kinds of diagrams. Such diagrams, arranged in classes, define how product and process items are related. This representation is known as meta-model [13]. However, UML is limited to representing only high-level functional requirements.

1.4. System Modeling Language

SysML basically uses various components of UML, but suggests two additional diagrams, called requirements and parametric diagrams. These diagrams help assisting the search, analysis, validation and documentation of requirements in addition to quantitative analysis [7]. A SysML model allows system visualization from various perspectives, maintaining consistency between them.

1.5. Boilerplates

A boilerplate is a template with some fixed syntax elements and variable parts to be filled in by engineers, during the requirements definition. This template allows the requirements formalization through textual expressions. Figure 1 shows system function, description, object related and performance values and units, which allow requirements traceability [14].

The <**bulkhead**> shall be able to <**carry**><**driver**> less than <**69**> <**dB**>

The <**system**> shall be able to<**function**> <**object**> less than <**performance**> <**unit**>

Figure 1. Boilerplate structure, adapted from [28].

1.6. ReqIF

The Requirements Interchange Format (ReqIF) is a standard XML-based to exchange and storage requirements between different tools. Through this standard, requirements can be accessed and managed by different stakeholders, which use different RM tools [15]. Therefore, ReqIF can be used as a strategy to export requirements of a SysML model and import it to other RM tools. Figure 2 shows the basic structure of ReqIF. The standard carries the requirement identification, a textual description, status and revision.

Figure 2. ReqIF structure, adapted from [29].

2. Methodology

The present research has been conducted based on DSR methodology (Design Science Research). This method aims to develop ways of achieving goals through a set of artifacts [16]. DSR must start with the identification of the research problem and solution goals. The next stage is to develop the model, evaluate it and report the results. Currently, the present research is in the development phase. Figure 3 shows the steps taken for the execution of this work [17] .

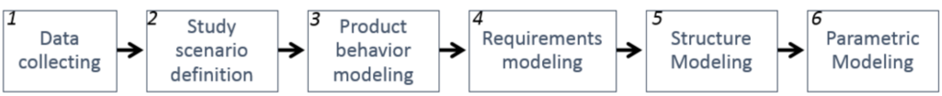

Figure 3. Work procedure steps.

Initially an information was collected in a partner company through interviews with key stakeholders of an agricultural tractor project (e.g. Marketing, Product Engineering, Manufacturing) in addition to the analysis of available project documentation. It was possible to identify discontinuity and ambiguity of requirements across the PDP. To facilitate future evaluation of the model, a tractor subsystem was chosen, named Vehicle System (i.e. tractor cabin), as study scenario. The requirements list was generated through documents provided by the department that performs product approval, in addiction to discussions with stakeholders.

3. Proposed Solution

Figure 4 shows an overview of the proposed model. The inputs are standardized information (i.e. ReqIF with boilerplates) which allow the SysML diagram building and establishing the relationships between then, represented by black connectors. The following sections further detail the steps taken to construct the model. The tool used for SysML modeling was Eclipse Papyrus due its open source characteristic.

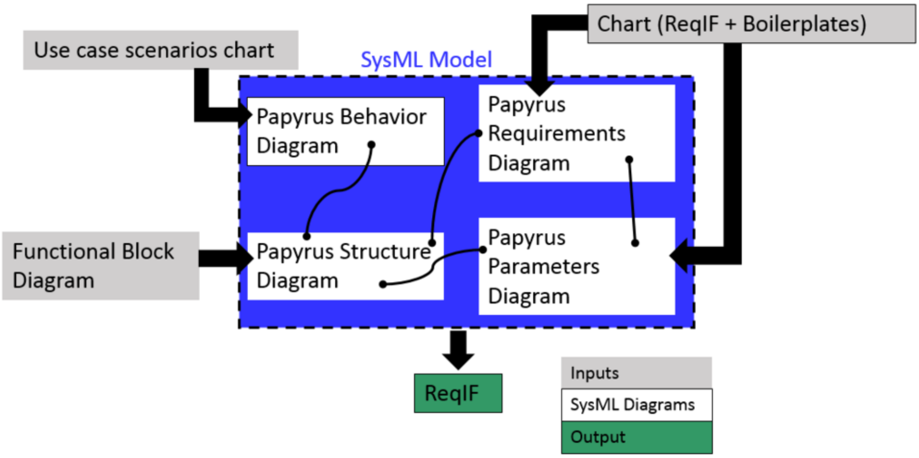

Figure 4. Proposed model concept.

3.1. Behavior modeling

The chart shown in Figure 5 presents use cases about the scenario, identified and described textually in order to guide the modeling of the Use Case Diagrams (UCD), which are one of the environmental diagrams types used in SysML for the purpose of describing the scenario of study. Each use case action is described in sequence, identifying the driver as an actor, and the subsequent actions (e.g. 'start tractor engine is a consequence of "turn ignition" action').

Based on the chart, the UCD was modeled, as shown in Figure 6. Lines link the actor to his actions, and the arrows indicate dependencies between actions (e.g. 'tractor only turns if the ignition is turned').

ID: UC1 NAME: Drive tractor Actor: Driver			
Main Scenario:			
1.	Open the door;	5.	Handle levers;
2.	Close the door;	6.	Press command buttons;
3.	Sit on the seat	7.	Turn ignition;
4.	Adjust seat;	8.	Start tractor engine

Figure 5. Use case scenario chart.

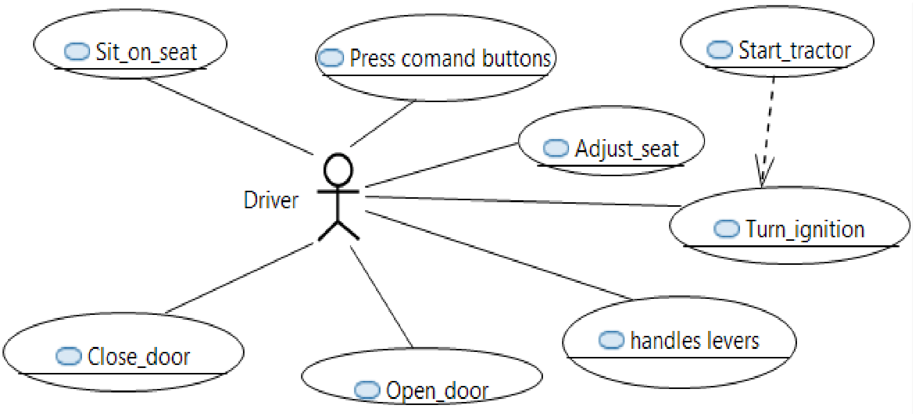

Figure 6. Use Case Diagram (developed in Papyrus).

3.2. Requirements Modeling

The information collected from requirements was in textual form, in several different documents. Therefore, for standardizing requirements, another chart was used, following the ReqIF structure, as shown in Figure 7. The field description was defined using boilerplates. The second column identifies the requirement constrain (i.e. brake pedal load). The chart allows one to figure out that the pedal has the function "support the user foot", and the maximum stress value is 180 MPa. Furthermore, it identifies the requirement category (i.e. functional) and the last two columns indicate early stages of the PDP (i.e revision 1.0 and 'starting' maturity)

Category	**Constraint**	**ID**	**Text**	**revision**	**maturity**
Functional	Brake_pedal_load	3.3	The **<brake_pedal>** shall be able to **<Support><user foot load>** less than **<180> <Mpa>**	1.0	Starting

Figure 7. Information input standard chart.

Based on the chart previously described, a Requirements Diagram (RD) was created in Papyrus, namely "Break pedal load", as shown in Figure 8. The RD shows that the part of the product that satisfies this requirement is the brake pedal, connected to the requirement by a dotted arrow labeled 'Satisfy1', which must be verified by a Finite Element Analysis (FEA) simulation, also connected to the requirements by a dotted arrow and labeled as 'Verify1'.

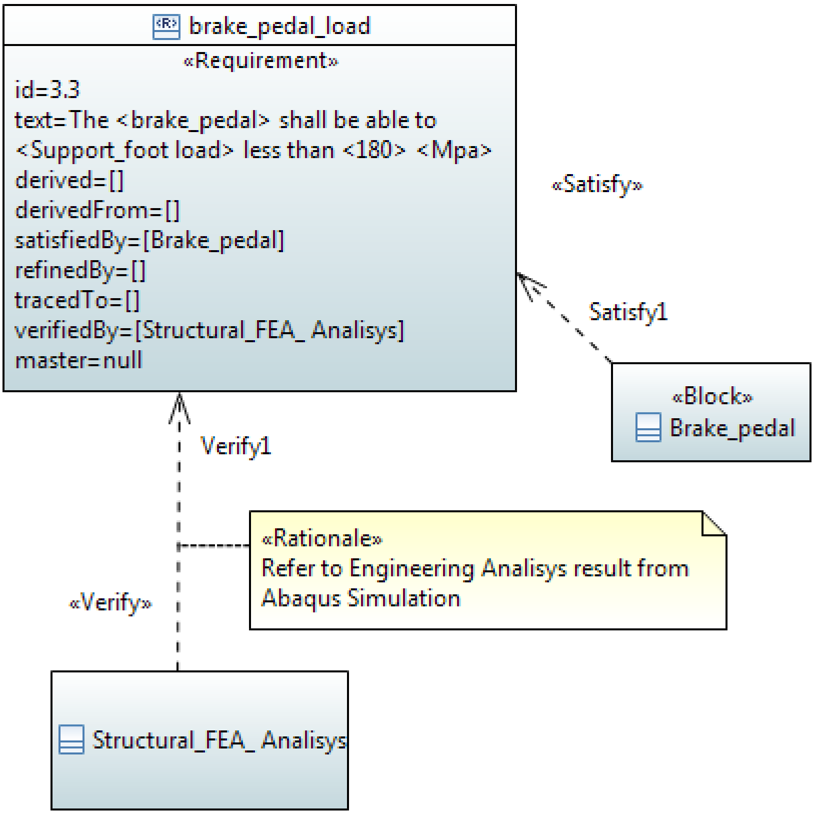

Figure 8. Requirements Diagram (developed in Papyrus).

3.3. Structure Modeling

Figure 9 shows the decomposition of the tractor structure, based on a product Functional Block Diagram (FBD), provided by the partner company. Each block represents a subsystem of interest (e.g. Vehicle System), and the lines represent its decomposition (e.g. "Structure System" is a "Tractor" subsystem, and "Vehicle System" is a "System Structure" subsystem). Besides the diagram in Figure 10, another diagram was created to represent the hierarchy of "Vehicle System" components. However due to its large size, it will not be illustrated in this paper.

3.4. Parametric modeling

In order to allow the verification of requirements constraints a Parametric Diagram (PD), as shown in Figure 10, was created. The "Brake pedal load" constraint was decomposed into two other constraints, representing the force and pressure equations. Thus the PD represents the system of equations to verify the requirement.

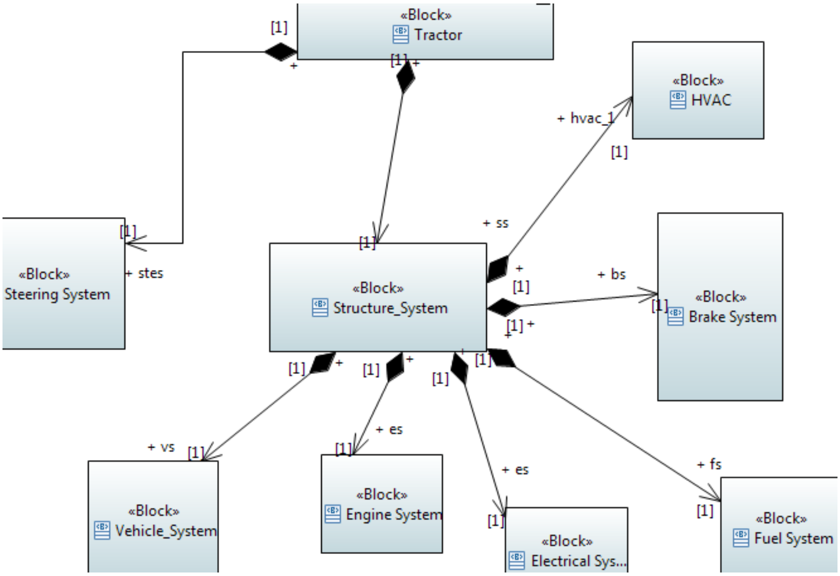

Figure 9. Structure Diagram (developed in Papyrus).

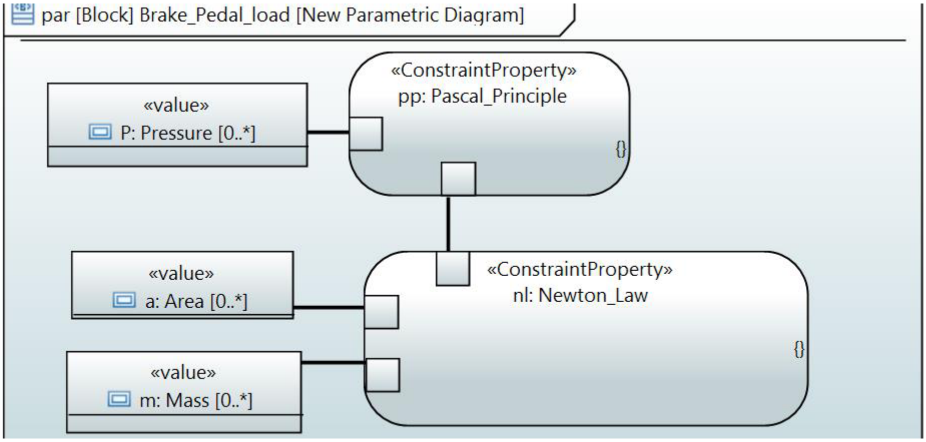

Figure 10. Parametric Diagram (developed in Papyrus).

3.5. Requirements traceability and changes control

The requirement control and traceability is possible through the link between the SysML model and a RM tool. As shown in Figure 11, the requirements specified in the model should be exported from Papyrus, through ReqIF standard and imported in RM tool. However, to allow the link between ReqIF and other model artifacts SysML (e.g. diagrams relations) an application is required to perform this function, which will not be addressed in this paper. In this way through the RM tool can perform the traceability requirements from SysML model. Changes in requirements along the PDP are controlled by ReqIF revision number, which should always be synchronized between the model and the RM tool. Creating new requirements will be carried out by importing new information ReqIF in Papyrus. The system engineer does the detailed specifications of new requirements and new correlations manually.

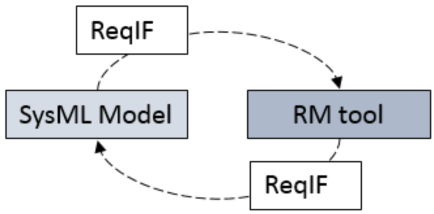

Figure 11. SysML control cycle.

4. Preliminary Results

The proposed model allows representing the correlation of the product with its subsystems' "vehicle system" and component "brake pedal" requirements (Q1). In addition, the ReqIF standard and boilerplates made it possible to formalize requirements, and consequently provided unique interpretation of requirements along the PDP (Q2). Thus, the proposed model allows the management and traceability of requirements, along the PDP, through correlations represented in SysML diagrams and the link with a RM tool (Q3).

5. Discussion

Research questions Q1, Q2 and Q3 of this study have been answered. However, to validate the proposed model, a more detailed system is necessary in order to verify if the concept allows consistence and continuity requirements in all PDP stages in the entire product. With this detailing, it will also be possible verify the validity of the proposed model for multiple related requirements within multiples subsystems, components and behaviors.

The critical task in this work has been the link of standardized information into ReqIF to SysML diagrams in Papyrus. In order to solve this issue, the next research step will be to apply a Papyrus plugin (e.g. ReqCycle) that supposedly allows this link. In addition, another important future research step is to demonstrate how ReqIF could be exported from SysML, allowing its use with other PLM tools (e.g. CAD, CAE).

6. Conclusions

This paper showed the great potential of SysML in the development of requirements, which key to all steps of a PDP. In addition, the importance of having a single model that centralizes all product gift information was highlighted, therefore not allowing ambiguities and discontinuities of information. Furthermore, this work shows the need to standardize requirements in the partner company, due to the large number and complexity of requirements in the tractor product, with several systems and subsystems, in addition to critical consequences that may occur to the product, due to missing requirements or mismodeling. Addition the requirements, there is the opportunity to apply SysML to control and manage other information along PDP (e.g. the Figure 10 structure diagram can provide an early product structure and be used as input to a bill of materials.

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An Elicitation Technique for Customer Emotional Requirements Based on Multi-Sensory User Experience

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Abstract. Satisfying customer's emotional preferences is the key to success in the new product design and development. In this regard, the semantic differential scale is a very efficient way to collect and analyse customer's subjective impression. It helps customers to express their attitudes through a list of words such as excited and enjoyment. This method, however, could be improved by a few fresh perspectives. Firstly, the semantic items often came from an ad-hoc project, and might not be appropriate because of individual differences. Secondly, it was assumed that customers seeing a product image can recall their feelings while human emotions are evoked by multi-sensory perceptions in a real life scenario. Some words, comfortable for instance, might be only triggered when you have the physical contact with the product. Designers named it as the actual product quality, the actual experience in a human-product interaction. This work therefore aims at investigating the elicitation technique to handle the nature of user experience, such as multimodality and expression preferences. Forty female road cyclists have provided their attitudes of positive emotions towards cycling following by an actual product quality evaluation of two bicycle saddles. The results showed the effect of personal involvement on a semantic differential scale and how users perceived certain Kansei words under different interactions, viz., vision, touch and cycling. Finally, the proposed elicitation technique could help manufacturers to build the design requirement based on customer's emotional preferences before pushing it into the target market.

Keywords. Customer requirement, user experience, multi-sensory, emotional design, bicycle saddle, semantic differential scale

Introduction

According to Kano's model [1], customer satisfaction is more than providing a functional product. Take a bicycle for example, it must be able to be steered. One's satisfaction will increase if the product helps the user perform the job better (e.g., pedalling smoothly and efficiently), while the affective quality of it can really delight your customers.

It is possible to design the predefined emotional impression on a product [2]; however, the customer emotional requirements are very subjective. Personal background and experience make it difficult to empathy other's emotional needs when the designer wants to predict whether a new concept prototype is enjoyable by

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customers. Human's feelings are also complicated. Compiling the objective data such as the electroencephalogram and the heart rate may be able to cope with the 'human error', but it can only detect the arousal level of signals, not identify the subtle feelings toward a product. For instance, customers may want to have a sporty bike; and sporty is an adjective that cannot be interpreted directly by any objective methods.

Inspired by the fact that the final evaluation is made up in customer's minds, Kansei Engineering [3] was introduced to close the gap between customer's emotional feelings and product properties. It also retrieves customer's feelings in a quantitative way, which is easier to be further translated into manufacturing specification.

1. The measurement of emotional requirement

Both quantitative and qualitative data can be collected for understanding customer's attitudes towards an industrial product. Semantic differential scales, for example, allow the respondents to rate their opinions on two bipolar items with opposite meanings (Figure 1). The original semantic items could be categorised into three dimensions, viz., evaluation, potency and activity by factor analysis [4].

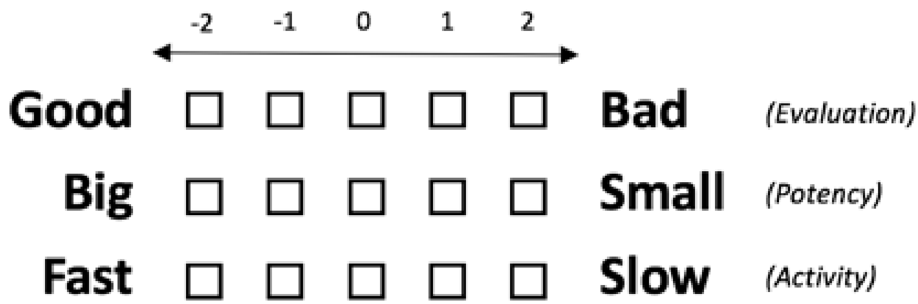

Figure 1. The concept of semantic differential scales.

1.1. Semantic items for product design

In the field of product design, the semantic items are commonly referred to as Kansei words. Designers apply semantic differential scales to build the semantic database for the Kansei engineering system. After collecting a large amount of Kansei words from magazines, the Internet, interviews and literatures, etc., a reduction process is therefore necessary for avoiding respondents get bored of a lengthy survey, or gets confused by the similar word pairs. In this regard, affinity diagram is usually carried out by experts grouping the similar Kansei words together; alternatively, some systematic approaches such as factor analysis, principal component analysis, cluster analysis or the combination of above methods can help organise the semantic items too.

The original semantic differential scale, after all, was instituted for identifying metaphorical meanings. When it comes to a commercial product, the structure of semantic dimensions may vary from study to study (Table 1).

Table 1. Examples in dealing with affective product quality.

Methods	Senses	Objects	Semantic dimensions	Individual profile
Exploratory factor analysis [4][5][9][10]	Visual	Automobile, sofa, kettle	trend, emotion, complexity, potency	N
	NA	Vague wordings	evaluation, potency, activity	N
	Visual Tactile	Hammer	quality, robustness, ergonomics, innovation, lightness, dynamic effects, efficacy	Y
Procrustes analysis [10]	Visual	Mobile phone	did not name the clusters	Y
Cluster analysis [10][11]	Visual	Home appliances	sport, cute, simple, rational, hi-tech, tender, traditional	N
	Tactile	Plastic	did not named the clusters	N
Principal component analysis [12]	Visual	Women's loafers/boots	activity/refinement, solidity/heaviness, mildness/firmness	N
Fuzzy theory [13]	Tactile	Insole	support, impact absorption, stimulus, aesthetic, massing effect, easy to use	N

For example, trend factor, emotion factor, complexity factor and potency factor [5] were extracted from three different product categories representing large, medium and small objects. Hsiao and Chen [5] suggested that the trend factor covers the most abstract meaning (e.g., contemporary-traditional) in comparison to the other three factors. Mugge, Govers [6]coined a type of semantic dimension, *product personality*, as the personality characteristics that people use to describe a product. Based on an investigation into cars and hoovers, they developed a universal scale of product personality with 20 words, viz., cheerful, open, relaxed, pretty, easy-going, cute, dominant, obtrusive, silly, childish, untidy, idiosyncratic, interesting, lively, provocative, modest, honest, serious, aloof and boring.

However, the similar content of trend factor and product personality indicates that the terminology is a challenge to provide comprehensive items for this self-reported survey. It raises awareness of clarifying the semantic dimension (covariance between semantic items), which can improve the efficiency of a semantic differential scale [7].

1.2. Semantic differential scales for multi-sensory experience

Despite the importance of clarifying the terminology issue, most research in sematic differential scales was based on the assumption that users can evaluate product experience via a photograph/image. Desmet, Nicolas [8] argued that the influence of visual appearance on product personality is bigger than its dynamic interaction; however, their hypothesis was tested on a custom prototype, not a commercial product. Besides, the quality of some product categories depends heavily on user's physical interactions, e.g., sport equipment.

On the other hand, research has showed that different emotions can be evoked by particular senses [8][14], for instance, the sound of a car engine contributes primarily to the driver's sense of safety. It implies that designers should take the senses into consideration regarding the semantic differential scales. Table 1 shows the technique of semantic differential scale was employed to evaluate products in several case studies; and how different systematic methods addressed the issue of semantic dimensions. Generally, only single sense (either visual or tactile) was tested in one study. Vergara, Mondragón [9] extended and tested the affective quality of hammers under four interaction levels, viz., seeing a photograph, seeing the physical product, touching it and using it. It also discussed the effect on participant's level of involvement as a professional, a DIY enthusiast or a trainee.

In summary, the authors argue that some guidelines of developing semantic differential scales which can elicit multi-sensory experience for sporting goods are needed.

2. Case study

An adapted semantic differential scale based on multi-sensory user experience was proposed, and will be integrated for training the Kansei engineering system afterwards. The bicycle saddle has been chosen to be the case study because it belongs to the sport equipment category and its wide range of potential participants (from recreational riders to competitive cyclists).

2.1. Unipolar scale with the positive item

It is known that the questionnaire layout will affect respondents' answers; the respondents tend to express their opinions more positively when the question is worded negatively [15]. Accordingly, the author suggests that the Kansei word evaluation should be in the unipolar format (Figure 2). Only positive items are listed because the affective product quality in fact is often considered as a bonus [1]; customer would not feel as dissatisfied as a failed must-be feature. In design practice, manufacturer will not aim for a bad product impression either; the antonym (e.g., beautiful-ugly) therefore shall not be included.

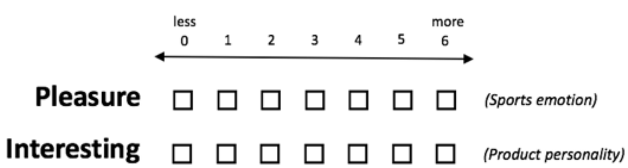

Figure 2. Unipolar semantic differential scale.

2.2. Multi-sensory data matrix and participant's profile

The responses can be classified into a data matrix (Figure 3). It is given a set of *i* participants on *j* scale, and *k* is the number of Kansei words, and has two predefined semantic dimensions, viz., *Sports Emotion* and *Product Personality*. Accordingly, the confirmatory factor analysis will be applied to compare the covariance between three senses, viz., vision, touch and cycling. In addition, individual profile will be another major index to interpret customer's preferences [16][17].

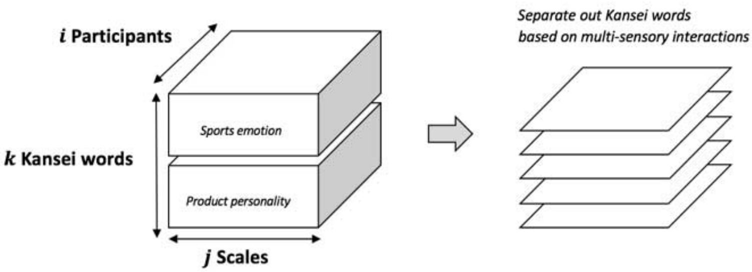

Figure 3. Data matrix for collected responses.

3. The experiment

The experiment aims at identifying the correlation between multi-sensory interactions and the semantic differential scale. It will test the hypothesis: When users approach the sport equipment in different ways (vision, touch, and cycling), they will express their feelings in certain semantic dimensions (sports emotion or product personality).

3.1. Selecting the Kansei words for cycling

Two semantic dimensions are defined: Sports Emotion (SE) and Product Personality (PP). The initial pool of SE is adopted from a study of questionnaire design with regards to the pre-competition emotions [18] including 26 positive attitudes, viz., Adrenaline Rush, Anticipation, Calm, Competitive, Confident, Content, Determined, Ecstatic, Elated, Energetic, Enjoyment, Enthusiastic, Excited, Exhilarated, Focused, Fulfilled, Happy, Important, Joyful, Motivated, Pleased, Pleasure, Proud, Relaxed, Relieved and Satisfied. Since the questionnaire was targeted only for competitive athletes, an online survey was conducted to learn how it performs for the general public. In other words, people who involve in sport activities with different motivations.

121 cyclists from the United Kingdom (UK) and 179 cyclists from Singapore (SG) have completed the survey choosing 5 out of 26 positive emotions based on their cycling experiences. The correspondence analysis was applied and the result was plotted in Figure 4 and Figure 5. The distance between ordinates (Kansei words) show their correlations towards cyclists' motivations, viz., Training, Sport, Commute and Leisure.

Due to the fact that the number of semantic items (Kansei words) will affect the structures of semantic dimensions [7]; first, any words under 1% selection percentage, viz., Important, Ecstatic, Joyful, Relieved, Excited, Anticipation, Adrenaline rush and Elated, was eliminated. It locates on the corner of the plotted chart showing a very weak relationship among all categories. Next, overlapped coordinates imply that its meanings are too similar to be distinguished by the participant. In this case, the one selected more frequently was assumed to be more understandable, and was kept on the list. For instance, Pleasure (7%) vs. Pleased (3%).

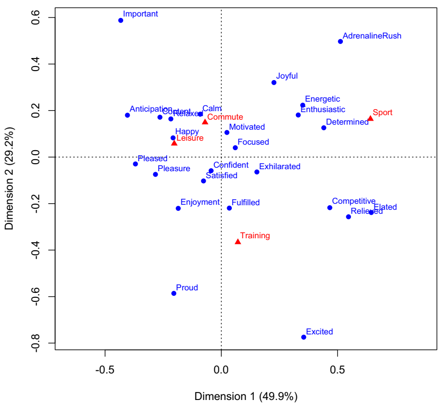

Figure 4. UK participants.

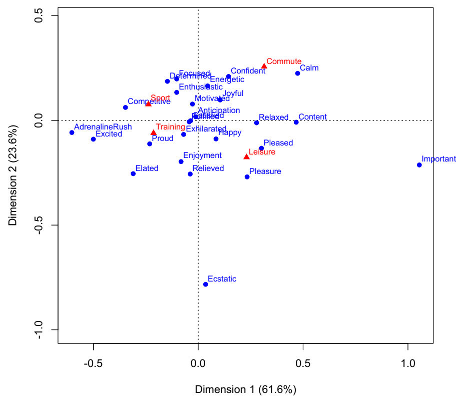

Figure 5. SG participants.

Subsequently, the initial pool of PP is combined from related studies. One is a product personality testing scale [6], however, it is suggested that if words also belong to SE, for instance, Cheerful, Lively and Relaxed, are not good reprehensive of PP. The ambiguous word with multiple meanings such as Open is not included either.

Since different emotions could be evoked from different product categories [14], the author further referred to one motorbikes project [19] that is not a ordinary commercial product like the coffee machine. The actual user experiences are similar between motorbikes and bicycles– Single rider on the two wheeled transportation vehicle. The idea is to select one Kansei word from each cluster of motorbikes personality: Formal, Traditional; Comfortable, Friendly, Popular, Professional; Emotional, Extraordinary, Heavy, International, Sharp, Sporty.

Next, some psycho-physical adjectives for the surface evaluation are collected because the customer's haptic perception is a crucial part of the actual product quality: Rough, Warm, Hard, Sticky [20]. The words that are repeated in studies above will be on a shortlist, for example, Easy-going or Friendly. Finally, 20 Kansei words are shown in Table 2.

Table 2. The final list of 20 Kansei words.

Semantic dimension	Kansei words
Sports emotion (SE)	Calm, Comfortable Competitive, Confident, Determined, Energetic, Enthusiastic, Pleasure, Proud, Relaxed.
Product personality (PP)	Cute, Dominant, Traditional, Friendly, Honest, Interesting, Pretty, Rough, Sporty, Warm.

3.2. Recruiting participants

Female regular road cyclists aged 18 or over who based in the England, were recruited in the second phase for the following reasons: Gender differences in expressing personal feelings [20], saddle pressure distribution [21] and the need for tactile interaction in a product evaluation [22].

Although some researchers argued that product personality is an overall impression on product appearance [6], participants indeed perceived specific emotions on different components for bicycles [16][22] relating to their previous experience [16]. In this regard, the authors noticed that four riding motivations might not be able to reflect true user experience. A cyclist can Commute to work on weekdays and Sport on weekend bike rides. Therefore, the authors developed the Individual Profile Index (IPI) which is similar to the test of dominant hand usage, and is based on the theory of Personal Involvement Inventory [23] for assessing user's level of involvement. There are 14 questions covering three aspects, viz., Personal, Facts and Situational so as to identify regular road cyclists. The more they involved into cycling, the higher score they got in IPI. The following are some sample questions:

Personal – I am a member of cycling club.
Facts – I ride my road bike three days or more in a week.
Situational – I get a saddle sore at some points during my riding.

3.3. Sessions

The participants will use adapted semantic differential scale to evaluate saddles models for three sessions respectively. The sequence of Vision, Touch and Cycling sessions was randomly assigned; all sessions were completed in one hour. The procedures in each session are explained in the following paragraphs.

Vision session: Past research showed that customers are more likely to purchase a product when they are given multiple options, i.e., make a final decision, therefore saddle samples are presented together to provide stronger emotional inductions. Each saddle has two photos of its top view and the side view shown on the laptop.

Touch session: The investigator put saddle samples on the desk, and the participants are allowed to touch it with hands. The above two sessions have no time limit.

Cycling session: This session requires the participants cycling on a bike ergometer, which uses a combination of air and magnetic resistance to deliver the distinctive feel of riding a bike out on the road. The participant must ride without padded bike shorts and ride at designated cadence (60rpm-110rpm). The ideal bike posture depends on cyclists' purpose of riding in addition to their body geometry and muscle strength. Professional race cyclists adjust their positions to perform maximum power output; however, the primary goal of bike fitting here is to reduce the risk of injury and discomfort.

After the bike posture is fit, each participant was asked to cycle at three handlebar positions for three minutes. The participants warmed up their body before sitting on the bike ergometer following by filling in the adapted semantic differential survey. Noted that there are half of them do not see which saddle they are riding on for Cycling session (blind group).

4. Results and discussion

Forty female regular road cyclists were volunteered to evaluate two saddles in the experiment. The average age of participants was 37 years (SD=12.2). The repeated-measures analysis of variance [24] was conducted; saddles, senses and Kansei words were set as within-subjects factors while individual profile index and blind group were set as between-subjects factors.

4.1. Analysis: influence of multi-sensory interaction on semantic dimensions

The average scores on each Kansei words for Saddle A and Saddle B are shown in Figure 6 and Figure 7. In general, there is a significant difference on Kansei words evaluation when the participants see (p=.001) or touch (p=.001) for either saddle. However, they seem to perceive similar emotional intensity when they ride on two saddles (p=.477). This result is not affected by whether they can see the saddles or not while riding (p=.199), in other words, the look of a bicycle seat might not be the major factor contributing to Cycling session.

Under different interactions, the participant perceived certain Kansei words including Relaxed (p=.019), Determined (p=.034), Confident (p=.009), Cute (p=.001), Warm (p=.001), Traditional (p=.012), Friendly (p=.001). Although four of them belong to the PP dimension, it does not have enough evidence to support authors' hypothesis.

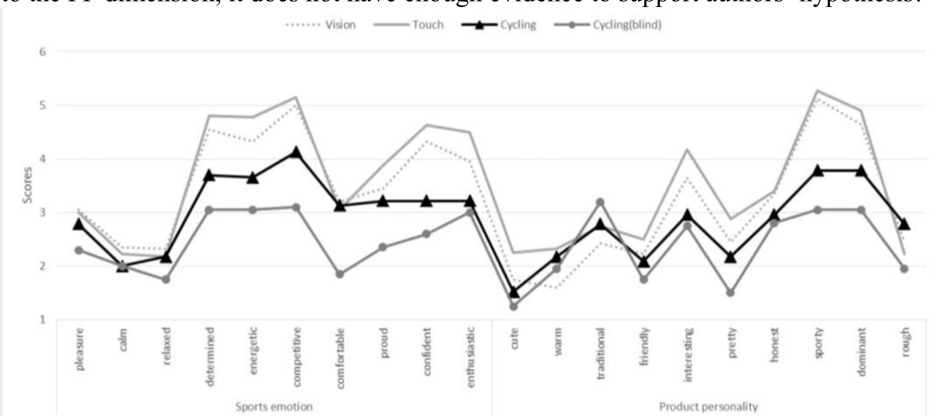

Figure 6. Average scores on 20 Kansei words for Saddle A.

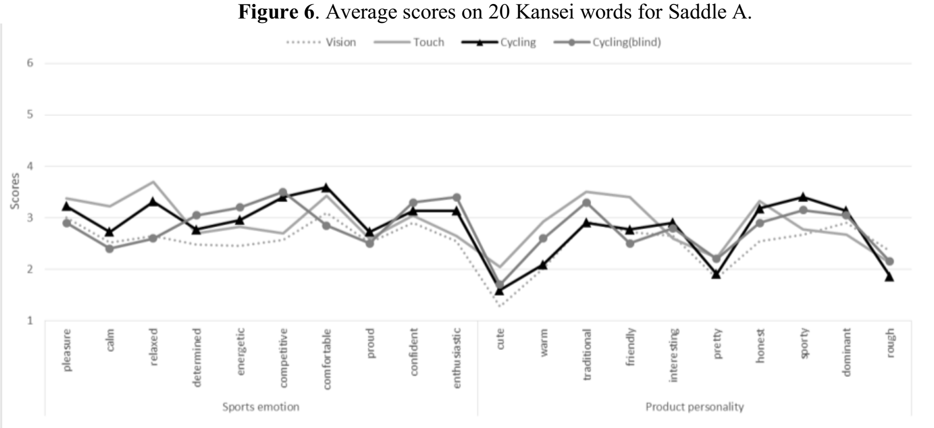

Figure 7. Average scores on 20 Kansei words for Saddle B.

Table 3. Compare the *p*-values on two saddles.

	Saddle A	**Saddle B**
Sense	.002*	.028*
Sense x blind	.013*	.360
Sense x IPI	.038	.632
Kansei x IPI	.284	.016*

Interestingly, the results can be better interpreted if the IPI, Individual Profile Index (p=.028) is set as between-subjects factor instead of single motivation (p=.306). Saddle A and Saddle B are discussed respectively in Table 3.

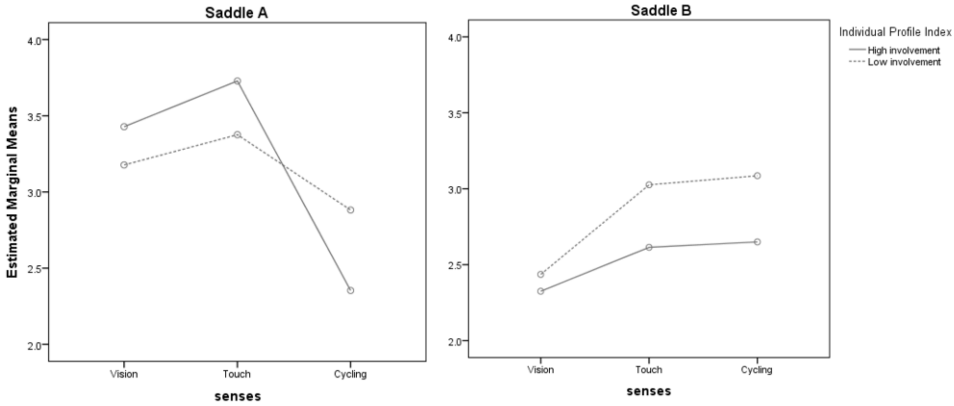

Figure 8. Estimated marginal means on multi-sensory interaction and individual profile index.

The effect of IPI on multi-sensory interaction for two saddles is shown in Figure 8. All participants tend to express more positive feelings towards Saddle A initially; however, the scores dropped more after higher involved cyclists ride on it. In contrast, they enjoy seating on Saddle B which does not give them a good first impression. The result is also consistent with previous studies that tactile input often benefits on product evaluation.

4.2. Constrains and future work

In this work, the actual product quality of bicycle saddles was limited to the seated cycling experience on the flat road. It presents some findings that could strength the contribution of semantic differential scale to Kansei engineering system, although the findings regarding the semantic dimensions are not enough to explain users' multi-sensory interaction.

The authors would like to extend the work to map user's affective responses into the product specification, for instance, the pad materials or pressure distribution. The technique will contribute to further study investigating the emotional requirement of sporting goods based on user's multi-sensory experience.

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Part 18

Supply Chain Collaboration

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Performance Measurement for Supply Chain Management: A Systematic Literature Review

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Abstract. Performance measurement models are evolving fast in recent years, many research studies have been done regarding the nature and the methodologies of measuring performance in organizations. The present global economic environment of continuous change is demanding new business models and competitive strategies. These new models are being characterized by integration, and new technologies adoption, their operations are being forced to look not only in individual company, but also in their entire set of operations networks. The present challenge is to extend the performance management and measurement models developed for isolated companies to supply chains. This article aims to systematically review the literature on supply chain performance management and measurement in order to map the trends and behavior of scientific production developed in the field.

Keywords. Performance measurement, Supply chain management, Supply chain performance measurement systems, Systematic literature review.

Introduction

The concept of performance measurement is progressing and in recent years, many research studies have been done regarding the nature and the methodologies of measuring performance in organisations [1]. This field developed over a number of phases, so ordered: productivity management; budgetary control; integrated performance measurement and integrated performance management [2].

With continuous changes happening in the world, in the new business environment, such as integration, and new technologies like the Internet, many organisations are forced to focus on the supply chain (SC) rather than their internal operations. Like this, the next step is to extend the performance management and measurement from isolated companies to supply chains. Aramyan *et al.* [3] put that an adequate performance measurement system needs to be developed in order to assess the success of supply chains.

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Therefore, measuring supply chain performance plays an important role in supply chain management and improvement, and has received a lot of attention from the research community so that measuring it can improve the understanding and the cooperation between SC partners [4], increases SC integration [5] and can reveal the gap between planning and execution, helping companies to identify potential problems and areas for improvement [6].

This article aims to systematically review the literature on supply chain performance management and measurement from the perspective of operations management, highlighting the factors that affect the supply chain performance, performance dimensions and decision areas. A bibliometric analysis was conducted in order to show the research evolution on this theme. This paper is organized into the following sections: description of the systematic review methodology used research trands based on the literature; findings and conclusions.

1. Systematic review of performance measurement and management in the supply chain

This paper undertakes a systematic literature review in seeking all the relevant papers about supply chain performance management e measurement and the factors that influence the SC performance.

A systematic review has many advantages over other types of reviews such as traditional reviews as a systematic review requires an extensive review of articles following a list of specific steps to ensure the most relevant information with regard to a specific topic (subject) is obtained in an unbiased manner. Eventually, this ensures the fidelity, completeness and rigorous nature of the review [7]–[9].

The systematic literature review was conducted by creating a dataset constructed based on six different databases: Web of Science, Scopus, Science Direct, Emerald, Taylor & Francis, and Wiley. These databases have important journals in the field of supply chain. Search was made for papers written in english and portuguese, at all times. The search criteria are as follows: The search expressions were divided into three groups: The first group of expressions related to SC (Supply Chain, SCOR, Operations Network, Collaboration Network, Extended enterprise, Supplier, Interorganizational). The second group consists of expressions that represent the measurement and performance management (Performance, Indicator, Metric, Measure, KPI, Performance Measurement, Performance Management). The third group was set up with the intention to find references about models and performance measurement practices in the supply chain referenced in the literature (Model; Framework, Process, Method, Technique, Tool, System). The expressions were used as search engine in the title, abstract and keywords. Papers related to humanitarian chains and services were not considered in the analysis.

In total 1252 papers were founnded in the six bases. All papers abstracts were reviewed in order to exclude not pertinent works to the research and to identify the main methodology of each article. Repeated papers among the databases were also excluded, resulting in a dataset of 816 papers. Then, an bibliometric analysis was to perform within the filtered set of papers in order to understand the evolution of the theme under various perspectives. Bibliometric studies were used as techniques for supporting SLR strategy and, the study applies them as a set of research methods to map the structure of knowledge in the researched theme. Thus, from the processing of information relating to the authors of the research, the publication of vehicles, research institutions and keywords can be evaluated trends and behavior of scientific production developed in a specific field [10], [11].

2. Research Trends

For performance measurement and management (PMM) companies to be effective, it has to fit the environment in which it operates. The environmental changes should be reflected in the strategies developed and deployed, and these strategic changes should affect the PMM system. One of the most important changes now a days is the increasing importance of the supply chain [12].

Wong *et al.* [13] wrote "A supply chain consists of a chain of suppliers and customers aiming to provide a product or service to the end customers", and the alignment within a SC is an emerging and important issue. Chae [6] wrote that supply chain performance measurement (SCPM) means a set of metrics and processes related to assessing and evaluating how accurate the planning is and how well the execution is carried out. Acording to Chen and Paulraj [14], measuring SC performance can facilitate a better understanding of the SC, positively influencing SC players' behaviour and improving its overall performance.

Literature reviews were conducted regarding SC in different contexts. Many researchers have suggested different measurement systems using the metrics of performance from different aspects. Arzu Akyuz and Erman Erkan [15] reviewed 24 articles from 1999 to 2009, and concluded the frameworks and models were still immature. Bhagwat and Sharma [16] determined the required performance measures and developed a model for performance evaluation, based on these selected measures using analytical hierarchy process (AHP) methodology. Gunasekaran, Patel and Mcgaughey [17] develop a framework for SCPM that provides a detailed 'measurement and metrics classification' and uses a survey aiming at assessing importance within each metric group. Gunasekaran and Kobu [18] offer a comprehensive review and classification for SC measurement and metrics. Arzu Akyuz and Erman Erkan [15] present some characteristics and requirements that new era performance measurement metrics should have. Beamon [19] categorised performance measures in the literature into two groups of qualitative and quantitative measures.

Some other researchers reviewed supply chain management within the context of sustainability. The study of Ahi and Searcy [20] identifyed and analyzed the metrics that have been published in the literature on green supply chain management (GSCM) and sustainable supply chain management (SSCM). Bhattacharya *et al.* [21] delineated a green supply chain (GSC) performance measurement framework using an intra-organisational collaborative decision-making (CDM) approach. Chin, Tat and Sulaiman [22] reviewed the extant literature on the relationship between GSCM, environmental collaboration and sustainability performance and propose a plausible conceptual model to elucidate the relationship between these three variables in the context of Malaysian manufacturing companies. Olugu, Wong and Shaharoun [23] reviewed various literatures on green supply chain performance measurement, environmental management, traditional supply chain performance measurement, and automobile supply chain management.

The influence of information technology (IT), information and knowledge sharing in the performance of the supply chain is also targeted by investigators. In their study, Byrd and Davidson [24] examined the impact of information technology (IT) on the supply chain through a survey of 225 large for-profit US firms. Based on the dynamic capabilities perspective and the view of a hierarchy of capabilities, Liu *et al.* [25] proposed a model to examine how IT capabilities affect firm performance through absorptive capacity and supply chain agility in the SC context. In their study, Baihaqi and Sohal [26] conceptualised and assessed several factors that influence the degree of information sharing in supply chains.

Melnyk et al. [37] suggest that SC operating in the current working environment should have the ability to provide one or more (blend) of the six basic outcomes depending on the customer/market requirements, which are cost, responsiveness, resilience, security, innovation and sustainability. The findings of a survey conducted by Ambe [27] revealed that quality, final product delivery reliability and cost were highly rated and the most important indicators for the South African automotive market. Terpend and Ashenbaum [28] examines the intersecting effects of power, trust and supplier network size on 5 dimensions of supplier performance (delivery, quality, cost, innovation and flexibility). Other authors developed their studies with a focus on delivery [29]–[31] and SC flexibility [32], [33].

Several authors based their studies on the Supply Chain Operations Reference (SCOR) model and Balanced Scorecrd [15], [34]–[43]. The SCOR model is a framework, being developed and maintained by the SC council, for examining the SC in detail through defining and categorizing the processes that make up the chain, assigning metrics to these processes and reviewing comparable benchmarks [34]. It is a flexible framework and a common language that can help companies improve their SC internally and externally [35]. Hwang, Wen and Chen [36] explored the relationship between the plan-do-study-act (PDSA) cycle of green purchasing and the SCOR purchasing/sourcing process and its performance indices/metrics. Ganga and Carpinetti [37] proposed a SC performance model based on fuzzy logic to predict performance based on causal relationships between metrics of the SCOR model. Based on the survey data from 232 companies that have obtained ISO 9000 certification, Li, Su and Chen [38] studied the five decision areas of the SCOR model by integrating quality assurance measures in the SC process. Collectively, ‘Plan’ and ‘Source’ decisions are more important to customer-facing supply chain performance (reliability, response, and flexibility), and ‘Make’ decisions positively affect internal-facing performance metrics (cost and asset).

Sellitto *et al.* [39] presented a SCOR-based model for performance measurement in supply chains (SC) and apply it in the context of Brazilian footwear industry. The model has two dimensions: SCOR processes (source, make, deliver and return) and performance standards adapted from original SCOR (cost, quality, delivery and flexibility). And Thunberg and Persson [40] evaluated construction material supplier and construction site performance according to the SCOR model.

Kaplan and Norton [44] BSC concept reflects an intent to keep score of a set of items that maintain a balance ‘‘between short term and long term objectives, between financial and non-financial measures, between lagging and leading indicators, and between internal and external performance perspectives’’ [45]. The importance of the balanced scorecard approach for SCPM is beyond discussion [15]. The BSC holds the potential to facilitate performance measurement for SC [46]. Although extensive studies have been recorded in the evaluation of SC efficiency through balanced scorecard (BSC), these studies do not focus on the relationships between the four perspectives of the BSC. Kim and Rhee [41] examined the impact of green supply chain management CSFs (critical success factors) on the BSC (balanced scorecard) performance by the structural equation modelling metodology. Jalali Naini *et al.* [42] proposed a mixed performance measurement system using a combination of evolutionary game theory and the balanced scorecard (BSC) in environmental supply chain management (ESCM). Kusrini, Subagyo and Masruroh [43] has developed an integrated model that combines the BSC with the SCOR to identify key indicators of SC performance based on strategic objectives of supply chain actors and for the government (regulator) especially with regard to public sector policy.

3. Findings

This section presents the bibliometric analysis results, including time distribution, publishing country, journals, authors, methodologies and keywords analysis.

3.1. Time distribution and publishing country

83% of the papers were published during the last ten years, almost 40% during the last three years. Figure 1 represents the the publications evolution over the years. The analyzed publications are from 55 different countries. The nine most representative countries are shown in Figure 2.

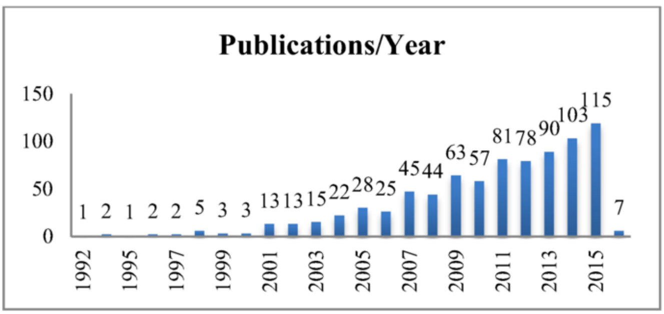

Figure 1. Amount of publications per year.

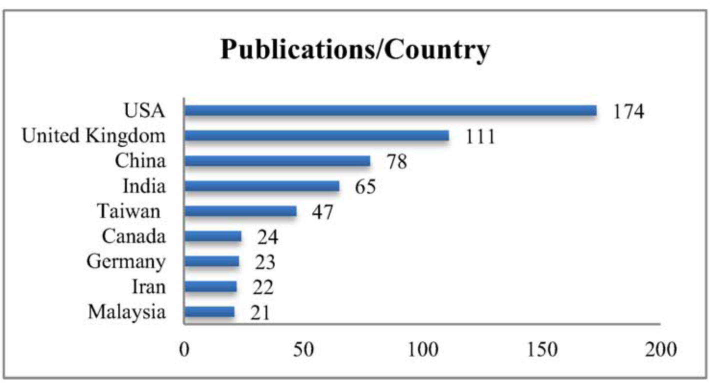

Figure 2. Amount of papers per country.

The fast growth of research may be justified not only by the strengthening of academic communities in general, but also by the increasing importance given to the supply chains management, which generates the need to develop ways to measure and manage the performance of companies working together.

Once the development of performance measurement went through the phases of productivity in the 50s, financial indicators until the 70s, measuring new dimensions from 80s, a change from measuring to managing performance in 90s, and only then aroused need for research in supply chain performance measurement and management, it was expected that the bulk of studies in the area had started to occur after 2005, with faster growth in recent years.

3.2. Journals

The 816 identified papers were published in 241 different journals. The ten most expressive journals, listed in Table 1 represented together 39% of all the papers.

Table 1. Papers distribution by journals.

Supply Chain Management: An international Journal	63
International Journal of Production Economics	58
International Journal of Production Research	48
International Journal of Operations and Production Management	37
Industrial Management and Data Systems	22
Benchmarking: An International Journal	21
International Journal of Physical Distribution and Logistics Management	20
Production Planning and Control	20
International Journal of Productivity and Performance Management	19
Journal of Operations Management	16

According to the databases, the subject area of the publications varies a lot. The most important fields interested in performance measurement and management of supply chain are (based on the amount of papers published): Business, Management and Accounting, Engineering, Decision Sciences, Computer Science, Economics, Econometrics and Finance, Social Sciences, Environmental Science and others.

3.3. Authors

Were considered for this analysis all authors of each identified paper, not just the correspondinng author. Were listed a total of 1.698 different authors, of which 80,6% are present in only one article. These data show a wide range of researchers interested in the topic, but points to a situation in which few of them use this theme as the main focus of their studies or research groups. Table 2 shows informations about tewelve authors who participated in six or more papers.

Table 2. Principal authors.

Authors	Number of papers	University/ Departament	Country	h-index
Sarkis, Joseph	11	Worcester Polytechnic Institute, School of Business	United States	54
Chan, Felix T.S.	11	Hong Kong Polytechnic University, Department of Industrial and Systems Engineering	China	42
Lai, Kee-hung	9	Hong Kong Polytechnic University, Faculty of Business	China	35
Fynes, Brian	8	National University of Ireland, Michael Smurfit Graduate Business School	Ireland	16
Huo, Baofeng	7	Zhejiang University, School of Management	China	10
Forslund, Helena	7	Linnaeus University, Department of Accounting and Logistics	Sweden	8
Tan, Keah-Choon	6	University of Nevada, Lee Business School	United States	22
Wiengarten, Frank	6	Universitat Ramon Llull, ESADE Business School	Spain	10
Zhao, Xiande	6	China Europe International Business School	China	25
Govindan, Kannan	6	Syddansk Universitet, Department of Technology and Innovation	Denmark	22
Green Jr., Kenneth W.	6	Southern Arkansas University, Department of Management	United States	23
Koh, S.C. Lenny	6	University of Sheffield, Management School	United Kingdom	27

3.4. *Methodologies and Keywords*

All papers on the dataset were classified by its most important methodological approach, based on the authors' description of their works. The following Figure 3 presents the amount of papers identified for each of these categories.

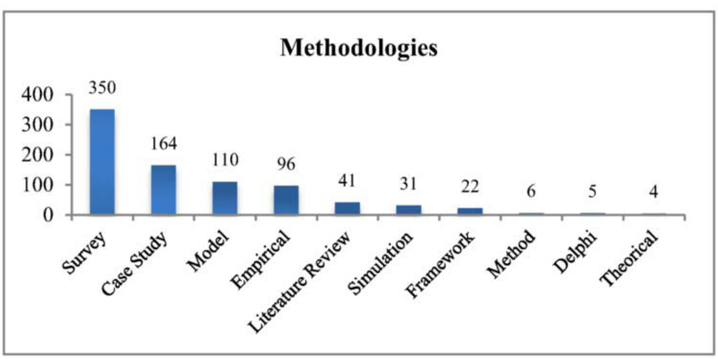

Figure 3. Amount of papers per methodological approach.

The most addressed keywords used for represent the studies in supply chain performance management, presented in the analyzed papers, were identified. Figure 4 lists the amount of papers studied that used the most cited keywords.

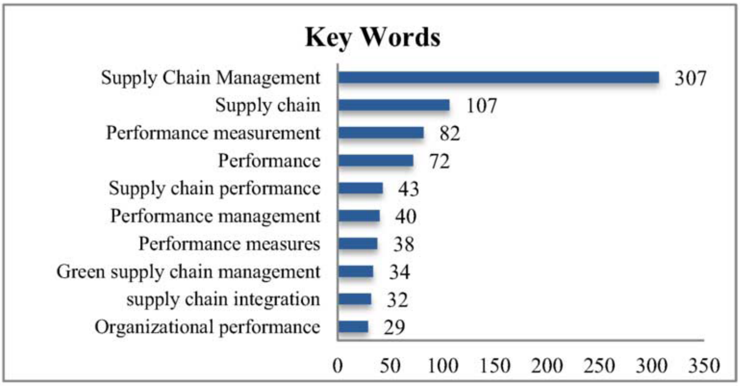

Figure 4. Principal keywords and number of publications.

4. Conclusion

The initial literature review showed many authors in the performance measurement and management field were pointing the need to extend the researches from companies to the SC context. Aiming to check if this calls for research were being answered, a Systematic literature review and bibliometric analysis, were conducted to map the search field.

The findings showed a greater amount of papers started to appear only in the last five years, publications are from journals from various areas and researchers from several countries. The diversity of research origins shows the importance of the theme and indicates it is continuing to grow in the future, but, in the other hand, hinders the search process maturity. Many papers have been conducted with the purpose of identifying the issues involved in supply chain performance measurement and management or proposing frameworks, models, and methods to solve them, but few studies have been made about application and validation of these proposals.

This paper contributes for theory in terms of mapping and reviewing the present research in the theme of Supply Chain Performance Measurement, and it creates conditions for academics to identify research opportunities in topics and research problems not fully addressed.

The main limitations of the approach are related to the selected scientific databases, document type (ie articles), language (i.e. English or Portuguese) and search phrases, which can delete items. The papers are not included in the data set may be pertinent to the field, but it is not likely that they would change the results of this evaluation. As future work, we propose an in-depth analysis on performance measurement models and indicators of the supply chain and consolidate in a conceptual framework, the supply chain performance measurement systems requirements proposed in the literature.

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Supplier Development on the Automotive Industry: A Bibliometric Study of the Scientific Production from 1993 to 2015

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Abstract. In the last decades, automobile manufacturers have been challenged with a continuous increase on global competition, customer's demands and economic instability which forced them to focus on their core competencies while having to outsource many of its operations and subcomponents. Adopting a quantitative approach on the scientific production of a specific field can be very helpful to deepen its understanding and to contribute to the forthcoming studies on the topic. The main objective of this study, therefore, is to quantitatively analyze what was published on supplier development area on the automotive context by the application of bibliometric techniques. In order to do so, the search string ((supplier development OR supplier performance OR supplier management) AND automo*) was applied on the ISI Web of Knowledge database, and the time frame was restricted to papers that were published within the years of 1993 to 2015, generating a sample of 60 papers. At the end, the results of descriptive statistics analysis identified the authors, articles, journals most referenced by scholars worldwide. This study becomes then an important contribution on the development of new ideas, concepts and approaches as well as on the consolidation of this field of research.

Keywords. Supplier development, automotive, bibliometrics

Introduction

One of the biggest paradigm shifts in modern business management is the fact that currently companies compete not individually among themselves, but in a systemic way within their respective supply chains [1]. Supply chain management (SCM) is the term used to describe the management of the flow of materials, information and resources through complete logical sequence of a production system, ranging from component suppliers, final centers until reaching the final consumer [2].

In this context, in addition to seeking a satisfactory level of efficiency and effectiveness in its internal operations, companies should improve the management of the relationship with suppliers and customers, as it may be an important source of competitive advantage. According to Germani et al. (2010) [3] and interaction styles (1) conceptual and design collaboration, (2) advanced design collaboration and finally interplay collaboration.

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Suppliers are a key factor for the performance of the purchasing company; they contribute, among other factors, to the quality, flexibility and cost of their products [4].

Through a close relationship with its suppliers buying companies are reducing their cycle time, reducing costs and increasing their capacity. This is especially true in industries that have complex products with a high dependency on suppliers such as the automotive assemblers. Thus, it comes as no surprise the fact that the vast majority of automobile manufacturers have formal development programs known suppliers as Supplier Development Programs (SDPs) [5].

In this sense, the present study aims to is to analyze the scientific literature on supplier development on the automotive industry quantitatively. The specific objectives are: (1) identify the authors and more relevant articles on the subject between 1993 and 2015; (2) Identify the most referenced journals on the subject; and (3) identify the main keywords. The methodological approach used is literature review, based on bibliometric theory.

This article is structured in five parts: (1) introduction; (2) a literature review that discusses the key concepts; (3) description of the sample selection method articles and analysis techniques; (4) results found; and finally, (5) conclusions and limitations of the work.

1. Literature review

The early research on inter-firms relationships did not viewed the competitive advantage of assemblers and suppliers in an integrative manner, thus different strategies were proposed to each company in their pursue to improve their operational performance [6]. The high-degree of interdependence between the intermediate component manufacturer and final assemblers in the products with high complexity began to be pointed out around the end of 1960s and beginning of 1970s by supply chain and organizational theory researchers such as Thompson (1967) [7] and Pfeffer and Slancik (1978) [8].

During the 1980s the concepts of value-adding relationships [9] and complementarities between the stages of the supply chain [10] were starting to emerge on the literature. These ideas suggested that buyers could obtain competitive advantage from the inputs of the supply chain [11] and benefit from the investment of assets in long term links with their key suppliers [12][13][14].

Leender (1966) [15] was this first author to coin the term “supplier development” to describe any efforts of assemblers to increase their range of possible suppliers and to improve their overall performance. More recently, Krause et al. (1998) [16] defined supplier development as any effort by an industrial buying firm to improve the performance or capabilities of its suppliers. These efforts are not limited to assist suppliers to comply their manufacturing parts with technical specifications but also encompass activities such as design of parts, adjustment of the manufacturing process; and specially, knowledge and information transfer [17].

With a considerable development of the conceptual basis of supplier management literature in the early 1990s a few important empirical studies that discussed the role of supplier development as a source of competitive advantage started to arise. The articles from Womack (1990) [18] and Clarck and Fujimoto (1991) [19], both applied on the automotive industry, are examples of comprehensive empirical studies done on the supplier development practices.

In particular the ability between a buyer and supplier to achieve a high level of coordination of its operations has been widely discussed in the literature and have been referred as the relational assets or relation-specific assets [20]. The relational approach states that in order to develop idiosyncratic communication routines buyers must be willing to share information, invest directly on suppliers operations, provide trainings and technical assistance. On the other hand suppliers are requested to share information, dedicate human resources and invest in equipment [21]. The practices above-mentioned are at the core practices of supplier development itself; for that reason, the application of such measures are expected to enhance the competitive advantage for both companies.

2. Methodology

The objectives described in the introduction are issue from selected research problem. The research was conducted in four steps, illustrated in Figure 1.

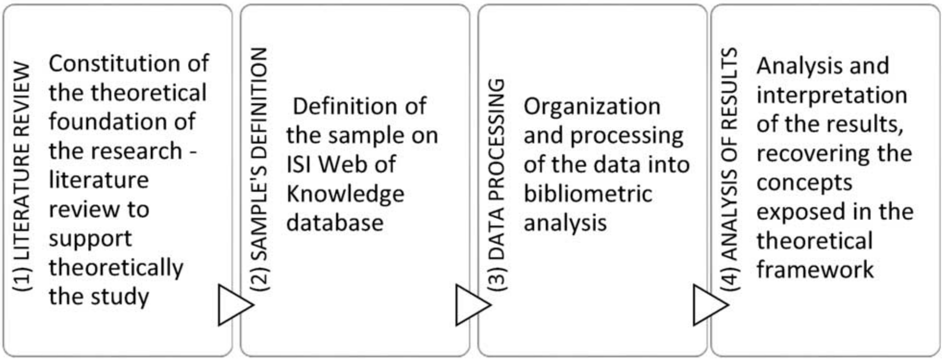

Figure 1. Research process.

2.1 *Bibliometrics*

The bibliometrics is defined as "a research technique that aims at the analysis of the size, growth and distribution of literature in a given field of knowledge." [22]. To Leite Filho (2006) [23], bibliometric performance indicators are important to evaluate academic research, guide direction and future research strategies.

Guedes and Borschiver (2005) [24] emphasize the aid of decision-making, organization and systematization of information allowed by this method. For these authors, it is a quantitative tool that minimizes the subjectivity of analysis.

Bibliometrics was developed by establishing empirical laws on the literature of behavior [25]. The bibliometric laws make use of mathematical and statistical analysis of data to investigate and quantify the scientific production on a subject.

In this scenario, it is important to know the three basic laws of bibliometrics to better understand the data: Zipf, Lotka and Bradford, the most commonly used and related scientific productivity [26].

The law of Zipf measures the number of occurrences of words in various texts, generating a list of terms in a particular subject being used to observe which scientific issue is addressed in the articles.

The law of Lotka covers the productivity (and quotes) of authors. It is based on the premise that some researchers publish a lot and that many scholars publish little.

The third law, called the Bradford law, allows to estimate the level of attraction of journals in a specific area of knowledge. In this case, since the first articles on a new subject are written and published by appropriate journals such vectors attract more articles on the topic in question; creating a feedback loop that accelerates the building of a positive image of certain journals in an area of knowledge.

The three laws are easily identified in the presentation of the results of this research. The first is associated with the main key expressions surrounding the theme of work. The second is reflected in the indication of authors with a more recognized production, measured by the number of citations and the article number. The third can be seen in the analysis of the leading journals on the topic.

2.2 *Sample definition*

The sample of articles on Supplier Development was set upon the selection of the database, the definition of the key words and search string, selection of the language of published articles, as illustrated in the Figure 2.

Criteria	Protocol Description
Keywords	Group 1- (supplier developement; supplier performance; supplier management) Group 2- (automo*)
Bolean Operator	OR between keywords, AND between groups
Search string	((*supplier developement* OR *supplier performance* OR *supplier management*) AND *automo**)
Text location	Title; abstract; keyword
Data Base	ISI Web of Knowledge
Language	English and Portuguese
Time window	From 1993 to 2015

Figure 2. Research protocol.

As for the determination of the database, we chose to use one the most popular platform for academic research - ISI Web of Knowledge [27] as it may return a representative sample of the scientific production on the topic.

In order to define the search string the authors read some of the seminal studies on the supplier development literature, and after testing a few key words on the database chosen the search string "((supplier development OR supplier performance OR supplier management) AND automo*)" was applied. It was considered only articles published in academic journals and conferences as they generally demand less time to be published and therefore provide a more updated picture of the recent studies on the subject. On the next step, a filter was applied so that only documents in the English and Portuguese language were taken into account. Without imposing restrictions on the years of publication, it was considered the years 1993-2015 time frame. The final composition of the sample resulted in 60 articles to be analyzed.

2.3 *Bibliometric treatment of collected*

The bibliometric treatment of the collected records are presented using descriptive statistics, obtained through illustrative charts and graphs generated by Microsoft Excel® software, highlighting three areas, based on bibliometric principles:

a) Classification of the most consulted journals;

b) Classification by most cited articles;

c) Classification of key expressions most used by the authors.

For the representation of the most used key expressions, it was applied the Wordle™ tool for building clouds of words, a concept that will shortly be defined later in this article. Moreover, it was possible to obtain other relevant information from the sample such as the evolution of the sample publications over time and who are the authors with the highest number of publications.

3. Findings

The first descriptive analysis of publications sought to identify how the interest on the supplier development topic behaved along the years, classifying the sample articles according to their year of publication. From the graph below (figure 3) can be observed that the development of the subject is fairly recent. The first publication date from 1993, and in subsequent years the volume of publications has a cyclical nature with publications volume peaks in the years 2010, 2011 and 2014, interspersed with periods of lower volume of publications.

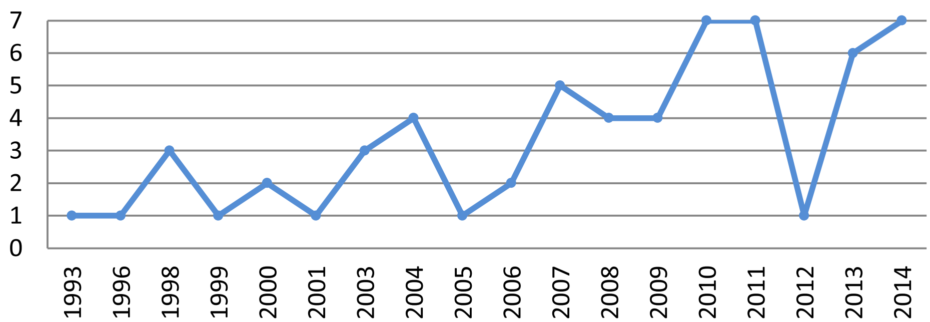

Figure3. Evolution of the sample publications over time.

A second descriptive analysis sought to evaluate the dispersion of work in order to identify the main authors, countries of origin and periodicals in volume of publications, as shown in Figures 4, 5 and 6.

With respect to the distribution of works per author (Figure 4), the analysis of the sample revealed that there are only 6 authors that published at least two articles, these authors are shown on the following figure. The author Jefrey K. Liker, from United States, stands out with the publication of four articles on the subject [28][29][30][31].

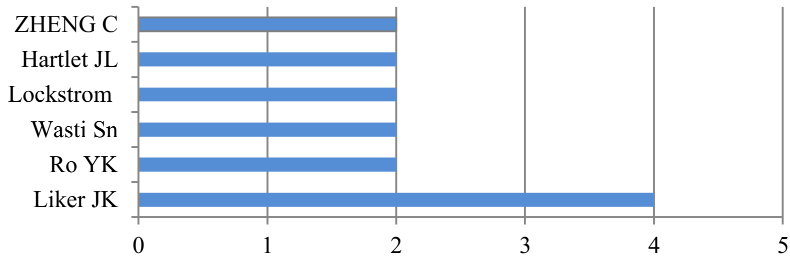

Figure 4. Authors with more publications.

The next analysis sought to identify the main centers of research that the authors are affiliated. Universities that stand out with more research on the subject are the University of Michigan, University of Cincinnati, both from the United States; Shanghai Jiao Tong University and Tongji University, both from China.

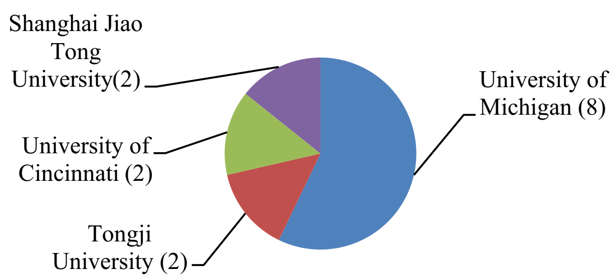

Figure 5. Universities with more publications.

Stratification of publications by country of origin of coauthors (Figure 6) shows a clear predominance of coauthors from USA. It is important to note that some papers have authors from different nationalities that's the reason one article could account to more than one country. Stratification contemplated all the countries of the sample, and Brazil had three publications.

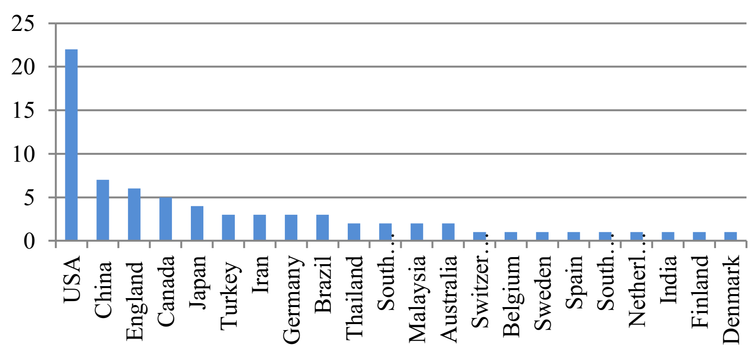

Figure 6. Distribution of the sample publications by country of origin.

Regarding the distribution of the sample articles per journal or conferences, the following graph (Figure 7) shows the journals or conferences with at least three publications. The International Journal of Production Economics had six publications on the topic followed by the Journal of operations management with five articles.

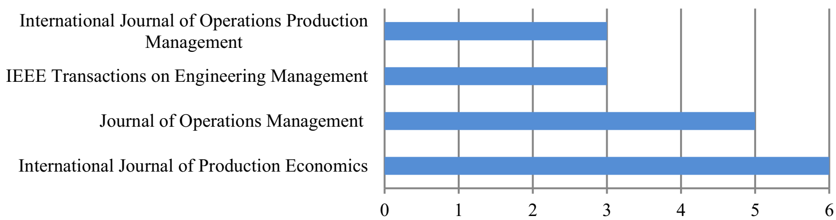

Figure 7. Distribution of publications by leading journals.

The 20 most cited articles of the sample are shown in Table 1. It is important to note that the data were collected on the ISI Web of knowledge database.

Table 1. The 20 most cited publications of the sample.

Articles	Number of citations
Kotabe, M; Martin, X; Domoto, H (2003)	286
Krause, Daniel R.; Handfield, Robert B.; Tyler, Beverly B. (2007)	203
Prahinski, C; Benton, WC (2004)	177
Liker, JK; Kamath, RR; Wasti, SN; Nagamachi, M (1996)	92
Richardson, J (1993)	87
Curkovic, S; Vickery, S; Droge, C (2000)	75
Schmitz, J; Platts, KW (2004)	57
Wasti, SN; Liker, JK (1999)	56
Wagner, SM (2006)	38
Stuart, I; Deckert, P; McCutcheon, D; Kunst, R (1998)	33
Rogers, Keith W.; Purdy, Lyn; Safayeni, Frank; Duimering, P. Robert (2007)	32
Zhang, Chun; Henke, John W., Jr.; Griffith, David A. (2009)	24
Ghijsen, Paul W. Th.; Semeijn, Janjaap; Ernstson, Saskia (2010)	23
Aksoy, Asli; Ozturk, Nursel (2011)	21
Ho, William; Dey, Prasanta K.; Lockstrom, Martin (2011)	21
Ro, Young K.; Liker, Jeffrey K.; Fixson, Sebastian K. (2008)	20
Tang, Dunbing; Qian, Xiaoming (2008)	20
Oh, Joongsan; Rhee, Seung-Kyu (2008)	20
Park, S; Hartley, JL; Wilson, D (2001)	19
Dyer, Jeff; Chu, Wujin (2011)	13

The citation analysis in general is based on the idea that authors cite documents they consider to be important for your own research. An article quoted many times can be a thought-provoking article, prominent, while it can be as Pilkington and Meredith (2009) [22], a negative quotation (quoting a reference as a bad example). However, the same authors claim that this is a problem that can be ignored.

The article of higher notoriety for the high number of citations is the Kotabe, M; Martin, X; Domoto, H (2003) [6]. This article examines links between knowledge transfer and relationship duration inter-firms, and more fundamentally what are the practices that buying firms adopts that enhance indeed the operational performance of supplier. This endeavor was conducted firms from both U.S. and Japan.

Another distinguish article from the sample is the Krause, Daniel R.; Handfield, Robert B.; Tyler, Beverly B. (2007) [16] work entitled “the relationships between supplier development, commitment, social capital accumulation and performance improvement”. With more than 200 citations, in this paper the authors sought to understand how buying firm commitment to a long-term relationship, sharing goals and values, supplier development programs and supplier dependency are related to buying firm operational performance improvements. The analysis was conducted on buying firms in the automotive and electronics industries on the U.S.

The word cloud, which are pictures made from words, is a form of linguistic data visualization that shows the frequency that words appear in a particular context [32-37]. In order to provide a clearer view of the words, the cloud of words (Figure 8) was limited to show the 50 most frequent words in the title, abstract and keywords.

Figure 8. Word cloud of the most cited words of the sample articles.

This analysis contributes to a clearer identification of the interrelatedness of the main themes. For example, the appearance of words such as "automotive", "Japanese", are a evidence that a large number of works are related to the supplier management practices adopted by Japanese automobile firms such as Kotabe, Martin and Domoto, (2003) [6]; Liker, Kamath, Wasti, SN and Nagamachi (1996) [28] and Richardson (1993) [38]. Another word that can be highlighted is “relationship(s)” showing that are several studies focused on how the relationship between the buying companies and supplier impact the overall performance of both or one of the firms.

4. Conclusion

To goal of this study was to characterize the state of the art of the research conducted in supplier development area applied in the automotive industry. The analysis and results described on this work constitute an important contribution to this field of research and practice. Above all, the main purpose of this research was to identify the main concepts that are being studied, as this is, normally, a starting point for scholars who aim to undertake studies on any field.

It is necessary also to point out some limitations of this study. The major limitation identified by the authors is the adoption of only one database for this bibliometric review. The ISI Web of knowledge database has a predominance of publications issued from north American journals written predominantly in English language, in this way not including the academic production of many countries, especially developing ones. Thus, many relevant papers may not integrate the sample of this study.

Finally, it was possible to identify in recent years an increased interest by scholars on the practices carried out by the buying companies for the development of its suppliers and how the application of these practices can contribute to the firm's competitive advantage. However, supplier development remains a young field of research that needs to be matured by practitioners and researchers on the years to come.

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Performance Measures to Humanitarian Logistics: The Perspective of the Humanitarian Assistance Chain

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Abstract. Earthquakes, hurricanes, floods, tsunamis and other emergency situations have demanded a special logistic treatment named Humanitarian Logistics, has currently been studied in several countries around the world. The goal of this article is to compare the performance measurement in the humanitarian supply chain to the traditional performance measurement in the commercial supply chain, to develop performance indicators in the humanitarian supply chain and present a structure that can be used as a basis for the development of a performance measurement system for the humanitarian logistics.

Keywords. logistics, humanitarian logistics, performance measures, humanitarian assistance chain.

Introduction

Some events such as the tsunami and earthquake in Asia, the hurricane Katrina, the earthquakes in China in, the earthquake and tsunami in Japan– among others – are demonstrating the vulnerability of modern societies, making evident a special logistics handling, which is being named humanitarian logistics. Many researches are being developed showing the relevance of humanitarian logistics for nations 0[2][3][4][5][6][7][8][9][10].

Many organizations of humanitarian assistance are handling many donations and a high volume of resources (the largest organizations handle billions of US dollars yearly). Currently, donors, agencies and volunteers can ask themselves: are humanitarian assistance organizations indeed practicing what they preach? Are their programs and projects efficient? The lack of resources, the increase in the frequency and dimension of disasters are requiring more transparent, efficient and effective operations. In this regard, the development of performance measures is becoming fundamental for all organizations involved in managing the humanitarian assistance chain.

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The article starts approaching concepts linked to humanitarian logistics. Following that, it compares the commercial supply chain to the humanitarian assistance chain. Next, humanitarian and corporate logistics regarding the characteristics linked to measures of performance are compared. Finally, the development of a system of performance measures to the humanitarian logistics is presented.

1. Defining Humanitarian Logistics

The definition of humanitarian logistics comes from the logistics objectives related to the commercial supply chain, i.e., beat time and distance in moving materials and services in an efficient and effective way.

Humanitarian logistics is the function that aims at the flow of people and materials in a proper and timely manner in the assistance chain, with the top objective of correctly serving the largest number of persons [1].

Humanitarian logistics are processes and systems involved in mobilizing people, resources and knowledge, in order to help vulnerable communities affected by natural disasters or complex emergencies. It seeks a fast response, aiming at serving the largest number of persons, preventing shortfalls and waste, organizing the many donations received in such cases, and above all act within a limited budget (International Federation of Red Cross, [11]).

The humanitarian logistics are the function demanded to ensure with efficiency and effectiveness the flow of supplies and persons, aiming at saving lives and ease the suffering of vulnerable persons (adapted from Thomas, [2]).

The concepts presented highlight that it is not enough being efficient, it is also necessary to be effective, i.e., under the eye of humanitarian logistics, help must reach its destination in proper and timely fashion, always focusing in easing suffering and preserving life.

In a general way, humanitarian logistics proposes the effective use of logistics concepts, adapted to the specifics of humanitarian assistance chains. These concepts may be the key differential to maximize the efficiency and response time to the emergency situation.

2. Commercial Supply Chain and Humanitarian Assistance Chain

The main objective in the commercial supply chain is to deliver the right products in the precise quantity to the correct location within proper timing. As such, the process involved encompasses all activities related to the flow and transformation of goods and information, from the start to the end point. In Figure 1, it is possible to see a commercial supply chain with four levels: supplies, production, distribution and consumers.

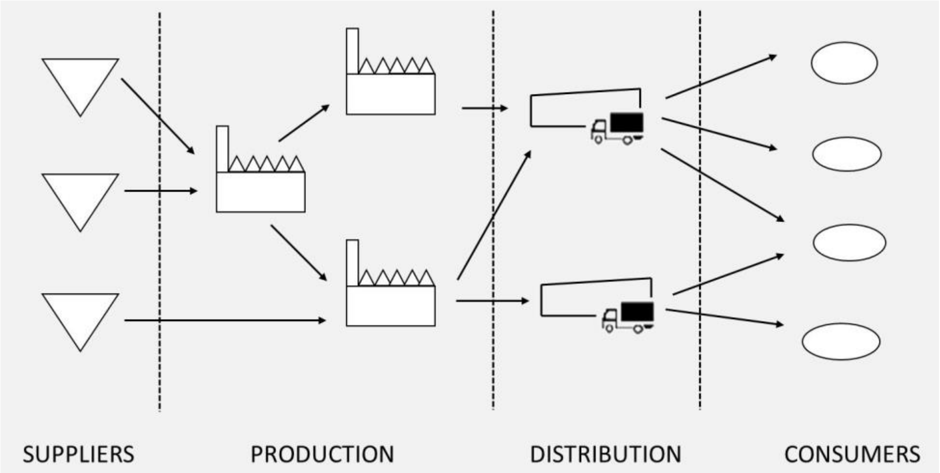

Figure 1: Structure of a commercial supply chain (adapted from Beamon, [12]).

Similar to a commercial supply chain, in the humanitarian assistance chain the flow of supplies, obtained from donors and/or suppliers, initially flows from pre-existent inventories. In general, supplies are transported from several locations in the world to a distribution center located in a strategic point. After that, supplies are carried to a second distribution center (typically located in a larger city). In such second distribution center, supplies are segregated, classified and transferred over to local distribution centers. At the end, supplies of humanitarian assistance are delivered to beneficiaries. The supplies purchased from local sources must also be sent to local distribution centers, or directly distributed to the beneficiaries (Beamon, [3]).

Since a disaster occurs, a humanitarian assistance organization generally uses a standard process. The basic structure of an assistance mission have 4 distinct phases (Thomas, [13]):

1. Assessment: Identification of needs based on the specific characteristics of the occurrence. In this phase few resources are needed.
2. Organization: Growing need of resources, according to the characteristics identified in phase 1.
3. Sustaining: Period during which operations are sustained and resources are kept.
4. Reconfiguration: Operations are reduced until finally they completely end.

3. Performance Measures

There is plenty of literature about performance measures and their application. However, most of existing researches focuses on corporate logistics and the services sector. Neely and Adams define a performance measure as being the process to quantify the efficiency and effectiveness of an action [14]. The same authors highlight that a performance measures system shall answer to questions such as: Are the measures aligned to the organization's goals? What is the focus of the measures (financial, clients, employees, suppliers)?.

According to Rouse & Putterill, there are many approaches or methods for performance measures, each with its own purpose [15]. These different approaches have their effective contribution, but in essence they are incomplete. Among these approaches, the models of business excellence, shareholder value frameworks, ABC, benchmarking and balanced scorecards are the ones that stand out.

The great challenge to establish performance measures, both in corporate and in humanitarian logistics, is in the degree of complexity of the chain, and in the traditional difficulties regarding what to measure and how to measure. Because of different characteristics for corporate and humanitarian assistance organizations, performance measures for the latter will also be different.

There are additional challenges to humanitarian assistance organizations, when they start to measure their logistics performance. Some authors suggest challenges such as: the intangible character of services provided; the magnitude and variety of missions; the different levels of interest. Sawhill & Williamson provide the following example [16]: "Imagine an organization whose mission is to ease human suffering. How can you measure such abstract notion? How can an organization obtain, in a relevant way, its direct contribution in such a broad mission? What criteria shall be taken into account to assess how successful a mission is?".

3.1. Performance Measures and Corporate Logistics

In a traditional corporate system, two performance measures are predominantly being used: cost and customer satisfaction. However, many types of costs are not quantifiable, and other types of measures are not easily converted into costs.

Within a corporate context, performance measures may be split into three types, according to Lindenberg & Bryant [17]:

1. Internal Measures: These measures include inventory levels, use of equipments, energy consumption, production costs, customization of orders, etc;
2. Flexibility Measures: In the midst of uncertainties, quick response to change and the development of a certain degree of flexibility is paramount. In this regard, the flexibility measures were created, with highlights for the following:
   - Volume flexibility: Allows changing the products' output level [18];
   - Shipping flexibility: Allows changing the schedule of shipping dates;
   - Mix flexibility: Allows changing the variety of products [19];
   - New products flexibility: Allows producing and launching new products in the market;
3. External Measures: These include sales, delivery time, response time to consumers, quality and quantity of finished goods.

3.2. Performance Measures and Humanitarian Logistics

Performance measures are not usually handled within the humanitarian assistance sector. However, organizations from the sector are beginning to pay attention to their importance and urgency, mainly due to the increased competition in fund raising and donations, and to improve visibility and to keep society posted on their affairs.

Poister highlights the relevance of developing performance measures in humanitarian logistics [20]. The author argues that such development of performance measures systems may help the managers of humanitarian assistance organizations in decision making and in improving logistics performance. Apart from that, when these systems are effectively planned and implemented, performance measures provide a return that encourages managers, employees, volunteers and donors to improve performance even further. Such systems may also help in assessing resources with more efficiency and effectiveness, catering for better controls in operations.

The characteristics inherent and exclusive to the humanitarian assistance environment bring great challenges related to the proper selection of performance indicators, and the development of appropriate measuring systems. As observed by Kaplan [21], and by Henderson et al. [22], the not-for-profit sectors, generally, will describe measures of performance through the number of donations and operating expenses. In spite of the fact that a humanitarian assistance organization's success depends, partly, of fund-raising, its performance is not linked to this aspect. Increasing gains or donations does not necessarily increase the quality of services provided and the organization.

Efficient and effective processes are fundamental for the humanitarian assistance organizations. Many of those who act in events of emergency nature assure that the use of concepts in these situations may immensely contribute to the success of an operation. In this regard, performance measures are important in assessing the execution of an operation and in providing society with information.

Contrary to the corporate context, in humanitarian logistics the life of people is always the top objective to be attained. It is known that conditions are specific and different from those faced by corporations. As such, in the sequence we will present the development of a performance measures system to humanitarian logistics, which aims at being the key contribution of this article.

4. The Development of a Performance Measures System to Humanitaria Logistics

In order to establish performance measures to humanitarian logistics, it is important to analyze it from an operational point of view, i.e., considering those receiving support as clients. This conceptual model recognizes the relevance of donors, but allows the process to focus efficiently and effectively in the humanitarian view.

Differently from corporate logistics, donors do not have means to check how humanitarian assistance organizations are employing their resources and serving their expectations. On the other hand, if humanitarian assistance organizations have instruments to measure their performance, and provide society with information, stability and an increment in donation levels may be attained.

The basic questions regarding the development of a performance measures system to humanitarian logistics are the same of those for a corporate system: What is the best measure? What are the most appropriate indicators? What are the relations between performance indicators and decision making variables? How individual indicators can be integrated in a performance measures system?

1. Internal Performance Measures: Allows humanitarian assistance organizations to estimate with higher accuracy the needs of resources for several missions and/or activities. Usually, the cost is the key indicator in traditional corporate logistics, in humanitarian logistics there are three main costs: procurement; distribution; and inventory carrying.

Procurement Cost: Unforeseeable demand patterns increase the complexity in relationships between suppliers and humanitarian assistance organizations. The uncertainties in demand also make it difficult to assess procurement, as generally it cannot be made prior to the disaster's occurrence. In this regard, it is difficult to have a control on the cost of supplies. As such, the internal performance measure of procurement cost must assess the effects of costs of procurement strategies (as per-disaster inventory control) against a post-disaster acquisition.

Distribution Cost: Frequently, humanitarian assistance organizations need to transport several materials, in large quantities, within a very short period of time. The unforeseeable nature of demand, in humanitarian logistics, difficult the development of reliable relationships and partnerships with transport companies. The diversity of locations in which disasters occurs bring a need for a variety of transportation means (trucks, trains, airplanes, helicopters, etc). Also, the use of local distribution companies may be needed to hit the "last mile". So, an internal performance measure in distribution shall assess the potential areas and specific transport means for each disaster type, aiming at reducing distribution costs.

Inventory Carrying Cost: Differently from procurement and distribution costs, not all humanitarian assistance organizations will have inventory carrying costs. This happens as only some humanitarian assistance organizations keep and operate their own centers of supplies and inventories. The control of inventories in humanitarian logistics is still a great challenge. The internal performance measure of inventories carrying costs shall assess the different types of costs related to stocks maintenance. For instance, if the humanitarian assistance organization stores many perishable items, then the costs related to losses shall be measured.

The internal performance measures may also include the development of IT systems, use of coordinated processes of people, materials and information, simulation systems, training in emergencies.

2. Flexibility Measures: In corporate logistics, a flexibility performance measure may assess the ability of a system to support variations in volume and time schedule of suppliers, manufacturers and clients. In humanitarian logistics, flexibility performance measures are special for two reasons: the focus (save lives and ease suffering) and the uncertainty of demand (location, type and magnitude). The inherent degree of uncertainty in an emergency requires high levels of flexibility. As such, we can define flexibility measures such as:

Flexibility of Volume: Flexibility to respond to different magnitudes of disasters. The performance measure of flexibility of volume may assess the number of first need items that a humanitarian assistance organization is capable of dispatching during the first stages of the mission. In short, it is linked to the different magnitudes of disasters.

Flexibility of Shipping: This is linked to the response time to the disaster and the flexibility of shipping to different locations, what may signify the success or the failure of an operation. The performance measure of flexibility of shipping may assess the time lapsed from the start of the disaster and the arrival of the supplies from the organization to the site.

Flexibility of Mix: This is linked to the different types of disasters and to the specificities of each case. The performance measure of flexibility of mix will assess the different types of items that are demanded and transported to the affected area. A flexibility measure for mix may assess the number of different items and the quantity of each of these that the humanitarian assistance organization can supply during a specific time frame.

3. External Performance Measures: They are directly linked to easing the suffering of people involved and to the number of lives to be preserved. In this regard, the following external performance measures can be defined:

Response time: In humanitarian logistics, response time is critical and many factors may contribute to it, such as, the proper estimation of the humanitarian assistance organization, procurement and delivery strategies, definition of transport, suppliers, etc. There are certain items that are especially needed during the first stages of any emergency (medicines, tents, personal hygiene items, basic foodstuff, clothing).

Supply of products: For corporate logistics there are many variants of this basic indicator, such as the number of units produced for each time interval, of each type of product, sold in each region, etc. In humanitarian logistics, an external performance measure of supply of products shall assess the quantity supplied of each item, in each region. A question that shall also be addressed is the impartiality, i.e., distribution of supplies in just and equal terms.

As in the corporate environment, humanitarian assistance organizations have their own specificities. The proposed performance measures system encompasses the general principles that shall be observed in defining the specific performance measures for each organization.

5. Final Considerations

This article aimed at comparing performance measures in the humanitarian assistance chain against traditional performance measures in commercial supply chain, highlight the characteristics of corporate and humanitarian logistics, and introduce a performance measures system to humanitarian logistics, which may be used by humanitarian assistance organizations and serve as basis for further developments.

The conceptual approach aimed at introducing a different view from the traditional one, the one of humanitarian logistics, launching the basis for the development of a systemic research of performance measures linked to humanitarian logistics.

It is important to highlight that the proposed performance measures system aimed at bringing the general principles, but that it mus be confronted against the specificities of each organization of humanitarian assistance and each type of emergency situation so that new indicators may be reflected.

Currently, the international community is recognizing that the magnitude, the number of affected persons and the recurrence of disasters produced by natural or other phenomena are increasing. In this regard, great challenges are presented to humanitarian logistics, highlighting: aspects related to infrastructure, location of assistance centers, coordination of processes (persons, supplies, information, materials), and, mainly, the development of performance measures that will assess all of these activities.

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