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Literature review on the technologies and applications of Logistics 4.0

Technische Universiteit Delft

Literature review on the technologies and applications of Logistics 4.0

by

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Preface

This paper provides a securely structured and comprehensive overview of Logistics 4.0. Hereby, the key elements of the term are securely constructed and described explaining the origin, vision, components and strategy of Logistics 4.0. Besides that, the technologies on which the strategy is dependent, a step-wise description of the implementation and the current situation are provided. All these elements are summarized in a final conclusion. The goal of this paper is to provide a comprehensive overview of Logistics 4.0 which a non-expert reader provides with enough information to have a full understanding of the concept of Logistics 4.0, the applicable technologies, implementation steps with implications and information regarding the current state.

I would like to thank Dr. Ir. Y. Pang for the provided support, knowledge and availability during this literature study.

J.J. Steendijk
Delft, May 28, 2018

Nomenclature

AGV	Automated Guided Vehicle
AI	Artificial Intelligence
BCS	Belt Conveyor System
CBM	Conveyor belt monitoring
CPS	Cyber-Physical System
ECD	Embedded Conductive Detection
ERP	Enterprise resource planning
GPS	Global Positioning system
HMI	Human-Machine-Interfaces
IBCMC	Intelligent Belt Conveyor Monitoring and Control
ICT	Information and Communication Technology
ILS	Intelligent Logistics system
IoS	Internet of Services
IoT	Internet of Things
IT	Internet Technology
IP	Internet Protocol
KBES	knowledge-based expert system
M2M	Machine-to-Machine
MES	Manufacturing Execution Systems
MEMS	Micro Electromechanical Systems
OPC-UA	OPC Unified Architecture
PIACON	Poly-optimal Integrated Adaptive Control
RAM	Random Access Memory
RFID	Radio-Frequency Identification
ROM	Read-Only Memory
SME	Small and Medium Enterprises

Contents

1

Introduction

1.1. General information and relevance

The fourth industrial revolution characterized by the increasing digitization and interconnection of products, value chains and business models has arrived in the industrial sector. The, so called, Industry 4.0 presents essential attributes, opportunities and challenges [39]. Stated in the Oxford Dictionary, logistics is the detailed organization and implementation of a complex operation [16] A manufacturing company, either small-scale or multinational, has importance to invest and improve their logistics. Certainly, the size of the company influences the complexity of the logistics. Despite the size, logistics are key indicators of the performances of a company. Currently, according to Deloitte's survey in 2015, the segment warehousing and logistics has undergone the least transformation to industry 4.0 while it offers one of the greatest potential for benefiting from this digital transformation [62].

Logistics 4.0 is a narrower term than Industry 4.0 in spite of having similar assumptions [71]. As Industry 4.0 has influence on the whole system, Logistics 4.0 influences the logistical sub-systems with the same vision.

1.2. Aim and focus of the study

The scope of this report is to provide an overview of the concept of Logistics 4.0 which securely describes each component of the concept with profound information regarding key technologies of Logistics 4.0.

This will happen in different chapters. Firstly, as Logistics 4.0 is a result of Industry 4.0, the concept of Industry 4.0 will be described thoroughly as it provides important background information. This includes fundamental technological inventions and the main strategy to accomplish the vision of Industry 4.0. Secondly, the concept of Logistics 4.0 will be described with information regarding the vision, main components and strategy. Thirdly, the technologies which embeds the theory of Logistics 4.0 are elaborated and finally the implementation and current state of Logistics 4.0 are discussed. The main question that will be answered in this literature study is formulated as:

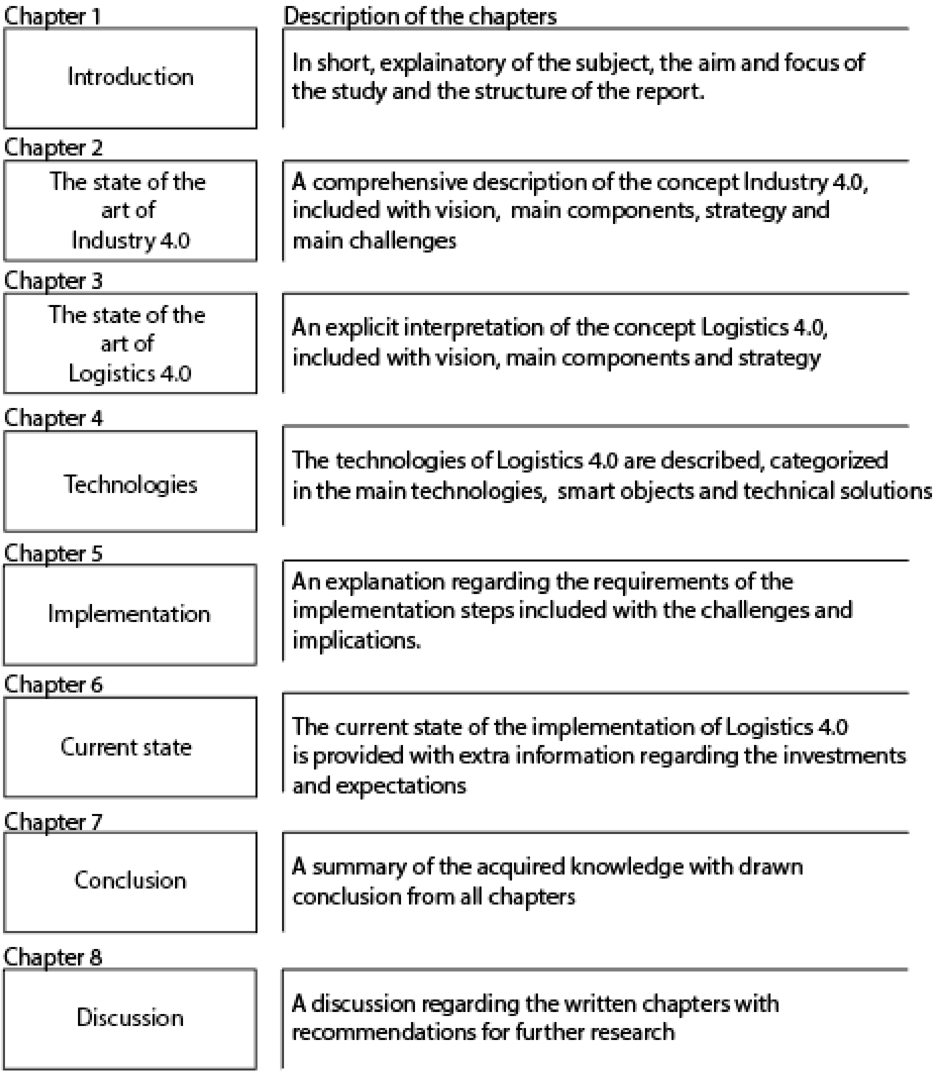
- *What is the concept of Logistics 4.0?*

To support these main questions and provide more insights regarding the subject, several sub-question are formulated, namely

- *What is the concept of Industry 4.0?*
- *What are requirement for logistics system to be specified as Logistics 4.0?*
- *Which technologies exist in the field of Logistics 4.0?*
- *What functionalities do the technologies offer?*
- *How can Logistics 4.0 be implemented in the logistics systems?*
- *What is the current state of Logistics 4.0?*

1.3. Structure of the report

The report starts with a thoroughly description of Industry 4.0 as it will provide background information in *Chapter 2 The state of the art of Industry 4.0*. This is followed by a description of Logistics 4.0 in *Chapter 3 The* *state of the art of Logistics 4.0* which defines the vision, main components and strategy of the theory. Subsequently, in *Chapter 4 Technologies*, the technologies which embed Logistics 4.0 are elaborated. *Chapter 5 Implementation* describes different ways to implement the technologies of Logistics 4.0 into a business. Finally in *Chapter 6 Current state*, the current state of the logistics system is provided. This acquired knowledge will be summarized in a conclusion in *Chapter 7 Conclusion* and a discussion is provided in *Chapter 8 Discussion*. The structure of the report can be seen in figure 1.1. With this structure, the reader will step-wise be provided with an overall understanding of Logistics 4.0.



Chapter		Description of the chapters
Chapter 1	Introduction	In short, explainatory of the subject, the aim and focus of the study and the structure of the report.
Chapter 2	The state of the art of Industry 4.0	A comprehensive description of the concept Industry 4.0, included with vision, main components, strategy and main challenges
Chapter 3	The state of the art of Logistics 4.0	An explicit interpretation of the concept Logistics 4.0, included with vision, main components and strategy
Chapter 4	Technologies	The technologies of Logistics 4.0 are described, categorized in the main technologies, smart objects and technical solutions
Chapter 5	Implementation	An explanation regarding the requirements of the implementation steps included with the challenges and implications.
Chapter 6	Current state	The current state of the implementation of Logistics 4.0 is provided with extra information regarding the investments and expectations
Chapter 7	Conclusion	A summary of the acquired knowledge with drawn conclusion from all chapters
Chapter 8	Discussion	A discussion regarding the written chapters with recommendations for further research

Figure 1.1: The structure of the report

2

The state of the art of Industry 4.0

In this chapter, a brief description of the state of the art of Industry 4.0 is provided as essential background information for Logistics 4.0. This chapter which is divided into several sections will securely discuss all elements of Industry 4.0. These sections begin, after a short introduction, with the vision of Industry 4.0. Thereafter, the main components are elaborated. Subsequently, the strategy for implementation is provided with some examples showing the influence of implementation. And finally the main challenge of Industry 4.0 and an overall conclusion is provided. During this chapter several technologies are mentioned, when these are more relevant and applicable for Logistics 4.0, these will be thoroughly discussed in chapter 4 *Technologies*.

Industry is the part of an economy that produces material goods which are highly mechanized and automatized. Ever since the beginning of industrialization, technological leaps have led to paradigm shifts which today are ex-post named "industrial revolutions": in the field of mechanization (1st industrial revolution), of the intensive use of electrical energy (2nd industrial revolution), and of the widespread digitization (3rd industrial revolution). On the basis of an advanced digitization within factories, the combination of internet technologies and future-oriented technologies in the field of “smart” objects (machines and products) seems to result in a new fundamental paradigm shift in industrial production. The vision of future production contains modular and efficient manufacturing systems and characterizes scenarios in which products control their own manufacturing process. This is supposed to realize the manufacturing of individual products in a batch size of one while maintaining the economic conditions of mass production. Tempted by this future expectation, the term “Industry 4.0” was established ex ante for a planned 4th industrial revolution [40]

Hermann summarized the origin of Industry 4.0 [29]: Industry 4.0 has its origin in Germany. In 2011, the German federal government announced Industry 4.0 as one of the key initiatives of its high-tech strategy. The fascinations for Industry 4.0 is twofold. First, for the first time an industrial revolution is predicted a priory, not observed ex-post. This provides various opportunities for companies and research institutes to actively shape the future. Second, the economic impact of this industrial revolution is supposed to be huge, as Industry 4.0 promises substantially increased operational effectiveness as well as the development of entirely new business models, services, and products.

In 2013, the key promoters, "Industrie 4.0 Working Group" and the "plattform Industrie 4.0" only described the vision with the basic technologies and not a clear definition. As a result, companies are facing difficulties when it comes to identifying and implementing Industry 4.0 scenarios. Design principles explicitly address this issue by providing a "systemization of knowledge" and describing the constituents of a phenomenon.

2.1. The vision

The essence of Industry 4.0 vision is the ubiquitous connection of people, things and machines. This connection is intended to produce a variety of new goods and services. Products, means of transport or tools are expected to “negotiate” within a virtual marketplace regarding which production elements could best accomplish the next production step. This would create a seamless link between the virtual world and the physical objects within the real world [39].

Industry 4.0 is focused on creating smart products, procedures and processes. Smart factories constitute a key feature of Industry 4.0. Smart factories are capable of managing complex systems, are less prone to disruption and are able to manufacture goods more efficiently. In the smart factory, human beings, machines and resources communicate with each other as naturally as in a social network. Smart products know the details of how they were manufactured and how they are intended to be used. It's interfaces with smart mobility, smart logistics and smart grids will make the smart factory a key component of tomorrow's smart infrastructures. This will result in the transformation of conventional value chains and the emergence of new business models [36].

The following aspects characterize the vision for Industry 4.0 [36]:

- A new level of socio-technical interaction between all the actors and resources involved in manufacturing. This will revolve around network of manufacturing resources (manufacturing machinery, robots, conveyor and warehousing systems and production facilities) that are autonomous, capable of controlling themselves in response to different situations, self-configuring, knowledge-based, sensor-equipped and spatially dispersed and that also incorporate the relevant planning and management systems. As a key component of this vision, smart factories will be embedded into inter-company value networks and will be characterized by end-to-end engineering that encompasses both the manufacturing process and the manufactured product, achieving seamless convergence of the digital and physical worlds. Smart factories will make the increasing complexity of manufacturing processes manageable for the people who work there and will ensure that production can be simultaneously attractive, sustainable in an urban environment and profitable.
- The smart products in Industry 4.0 are uniquely identifiable and may be located at all times. Even while they are being made, they will know the details of their own manufacturing process. This means that smart products will be able to control the individual stages of their production semi-autonomously. Moreover, it will be possible to ensure that finished goods know the parameters within which they can function optimally and are able to recognize signs of wear and tear throughout their life cycle. This information can be pooled in order to optimize the smart factory in terms of logistics, deployment and maintenance and for integration with business management applications.
- In the future of Industry 4.0, it will be possible to incorporate individual customer- and product-specific features into the design, configuration, ordering, planning, production, operation and recycling phases. It will even be possible to incorporate last-minute requests for changes immediately before or even during manufacturing and potentially also during operation. This will make it possible to manufacturing one-off items and very small quantities of goods profitably.
- Implementation of the Industry 4.0 vision will enable employees to control, regulate and configure smart manufacturing resource networks and manufacturing steps based on situation- and context-sensitive targets. Employees will be freed up from having to perform routine tasks, enabling them to focus on creative, value-added activities. They will thus retain a key role, particularly in terms of quality assurance. At the same time, flexible working conditions will enable greater compatibility between their work and their personal needs.
- Implementation of the vision for Industry 4.0 will require further expansion of the relevant network infrastructure and specification of network service quality through service level agreements. This will make it possible to meet the need for high bandwidths for data-intensive applications and for service providers to guarantee run times for time-critical applications.

2.2. Main components

Industry 4.0 is the superposition of several technological developments that embraces both products and processes. Industry 4.0 shall be defined as the embedding of smart products into digital and physical processes. Digital and physical processes interact with each other and cross geographical and organizational. This means that the physical production steps are accompanied by computer-based processes [63]

The Industry 4.0 Working Group mentioned the following main components of Industry 4.0 [36]:

- Cyber-physical Systems (CPS) are the new class of engineered systems which offer close interaction between cyber and physical components. Khaitan and McCalley describe CPS as the systems which offer integration's of computation, networking, and physical processes, or in other words, as the systems where physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a myriad of ways that change with context [38].

In the manufacturing context, this means that information related to the physical shop floor and the virtual computational space are highly synchronized. This allows for a whole new degree of control, surveillance, transparency and efficiency in the production process. With regard to their structure, CPS have two parallel networks to control, namely a physical network of interconnected components of the infrastructure and a cyber network comprised of intelligent controllers and the communication links among them. CPS realize the integration of these networks through the use of multiple sensors, actuators, control processing units and communication devices [33].

Khaitan and McCalley summarized the characteristics of CPS [38]. Some of the defining characteristics of CPS include (1) cyber capability in every physical component, (2) high-degree of automation, (3) networking at multiple scales, (4) integration at multiple temporal and spatial scales and (5) reorganizing/configuring dynamics . Due to the close interaction between cyber and physical worlds, several challenges exist in the design of CPS. To enable seamless integration, the events in physical world need to be reflected in the cyber world and the decision taken by the cyber world need to be communicated to the physical world. Both these actions need to be performed accurately and in timely manner. Thus, CPS need to coordinate between heterogeneous systems which consist of computing devices and distributed sensors and actuators. The sensors and actuators provide an interface between the physical and cyber worlds, and to adapt to the time varying physical and cyber context, effective policies are required.

- Internet of Things (IoT), in the simplest term, seems to envisage a society where all members have access to a full-fledged internet environment populated by self-configuring, self- managing, smart technology anytime and anywhere. Implicitly, the driving force for this expansive technology is to facilitate practices, increasing convenience. As defined by Sundmaeker [69] "IoT is a dynamic global network infrastructure with self-configuring capabilities based on standard and inter-operable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network" [54].

  In Industry 4.0 it can be considered as smart, connected products offer exponentially expanding opportunities for new functionality, far greater reliability, much higher product utilization, and capabilities that cut across and transcend traditional product boundaries [58].

  Sundmaeker categorizes the "things" in a hierarchy of five domains [69]. At the lowest level, domain 1, there are real world entities or virtual entities that communicate with each other and with infrastructure. At domain 2, things can compete with other things regarding resources and services. They can be equipped with sensors and therefore interact with the environment. Higher up, at domain 3, they can communicate and collaborate with other things and create groups or networks. More power is given to things at domain 4, at which level they are considered autonomous. Here, they can negotiate and adapt to their environment, they can also extract information and patterns from environment. They are expected to be able to learn, take decisions and reason. At the highest level, domain 5, things are capable of self-replication, controlling, creating, managing and even destroying other things.

- Internet of Services (IoS): It is often said that we are living in a so-called "service society" these days [3]. With respect to that, there are strong indications that, similar to the IoT, an IoS is emerging, based on the idea that services are made easily available through web technologies, allowing companies and private users to combine, create and offer new kind of value-added services [78]. It can be assumed that internet-based market places of services will play a key role in future industries. Barros and Oberle propose a broader definition of the term service, namely a commercial transaction where one party grants temporary access to the resources of another party in order to perform a prescribed function and a related benefit. Resources may be human workforce and skills, technical systems, information, consumables, land and others [7].

  The vision of the IoS is to enable service vendors to offer their services via the internet. Depending on the possible degree of digitization services can be offered and demanded world-wide. The IoS consists of participants, an infrastructure for services, business models and the services themselves. Services are offered and combined into value-added services by various suppliers; they are communicated to users as well as consumers and are accessed by them via various channels [14].

- Smart factories: up to now, CPS, IoT and IoS were introduced as core components of Industry 4.0. It must be noted that these concepts are closely linked to each other, since CPS communicate over the IoT and IoS, therefore enabling the so-called smart factory, which is built on the idea of a decentralized production system, in which “human beings, machines and resources communicate with each other as naturally as in a social network” [36]. The close linkage and communication between products, machinery, transport systems and humans is expected to change the existing production logic. Therefore, smart factories can be considered another key feature of Industry 4.0. In the smart factory, products find their way independently through production processes and are easily identifiable and locatable at any time, pursuing the idea of a cost-efficient, yet highly flexible and individualized mass production. The smart factories will make the increasing complexity of manufacturing processes manageable for the people who work there and will ensure that production can be simultaneously attractive, sustainable in an urban environment and profitable [36]. Hence, the potentials that might come along with smart factories are expected to be huge. It is important to understand that not only production processes but also the roles of employees are expected to change dramatically. Spath expect employees to enjoy greater responsibility, to act as decision makers and to take on supervising tasks instead of driving forklifts, for instance[67]. In the same context, some critics have recently pointed out that the automated and self- regulating nature of the smart factory might cause severe job destruction. However, hardly any reliable study supports that fear [33].

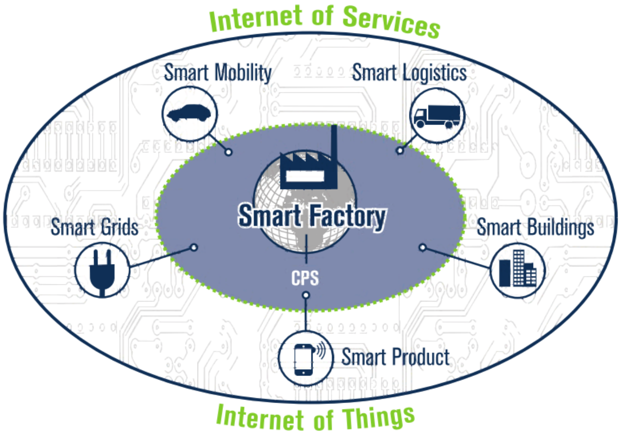


Figure 2.1: Main components of Industry 4.0 [36]

These main components are supported by smart object shown in figure 2.1. These other terms are all smart. They know not only about the process steps already passed through, but are also able to define future steps. These steps include not only productions steps still to be performed on the unfinished product, but also upcoming maintenance operations. The capability to individually specify its properties can be used for an individual production with varying size. Smart products interact with their physical environment. They are capable to perceive and interact with their environment [63].

Schmidt defines the abilities of smart product [63]. The concept of smart products defines the products which have the ability to do computations, store data, communicate and interact with their environment. For example Radio-Frequency Identification (RFID) technology that enables products to identify themselves. Smart products are able to communicate information about the steps already passed through but also are able to define future steps. They are capable to interact with their environment, for example, sensors allow to capture physical measures, cameras to get visual information on the product and its environment in real time, as well as the actuators enable the products to impact physical entities in their environment without human intervention.

2.3. The strategy

The strategy is defined by the Industry 4.0 Working Group [36]. The fourth industrial revolution holds huge potential for the manufacturing industry. The development of CPS technology offers significant opportunities for exporting technologies and products. The implementation of Industry 4.0 should aim to leverage the market potential for the manufacturing industry through the adoption of a dual strategy comprising the deployment of CPS in manufacturing on the one hand and the marketing of CPS technology and products in other to strengthen the manufacturing equipment industry. The key is now to find smart ways of combining outstanding technological solutions with the new potential offered by Information Technology (IT), in order to achieve a quantum leap in innovation. It is this systematic combination of information and communication technology with traditional high-tech strategies that will enable rapidly changing markets and increasingly complex global market processes to be managed so that companies can carve out new market opportunities themselves.

Optimal delivery of Industry 4.0 will only be possible if the leading supplier and leading market strategies are coordinated to ensure that their potential benefits complement each other. Hereafter, this approach will be referred to as the dual strategy. This strategy incorporates three key features:

- Development of inter-company value chains and networks through horizontal integration.
- Digital end-to-end engineering across the entire value chain of both the product and the associated manufacturing system.
- Development, implementation and vertical integration of flexible and re-configurable manufacturing systems within businesses.

These features are the key enablers for manufacturers to achieve a stable position in the face of highly volatile markets whilst flexibly adapting their value creation activities in response to changing market requirements. The features outlined under this dual CPS strategy will allow manufacturing companies to achieve rapid, on-time, fault-free production at market prices in the context of a highly dynamic market.

2.3.1. Horizontal integration through value networks

Horizontal integration refers to the integration of the various IT systems used in the different stages of the manufacturing and business planning processes that involve an exchange of materials, energy and information both within a company (e.g. inbound logistics, production, outbound logistics, marketing) and between several different companies (value networks).

These new value-creation networks are real-time optimized networks that enable integrated transparency, offer a high level of flexibility to respond more rapidly to problems and faults, and facilitate better global optimization. Similar to networked production systems, these (local and global) networks provide networking via CPS, from inbound logistics through warehousing, production, marketing and sales to outbound logistics and downstream services. The history of any part or product is logged and can be accessed at any time, ensuring constant trace-ability (a concept known as 'product memory').

This creates transparency and flexibility across entire process chains – from purchasing through production to sales, for example, or from the supplier through the company to the customer. Customer-specific adaptations can be made not only in the production but also in the development, ordering, planning, composition and distribution of products, enabling factors such as quality, time, risk, price and environmental sustainability to be handled dynamically, in real time and at all stages of the value chain, as can be seen in figure 2.2.

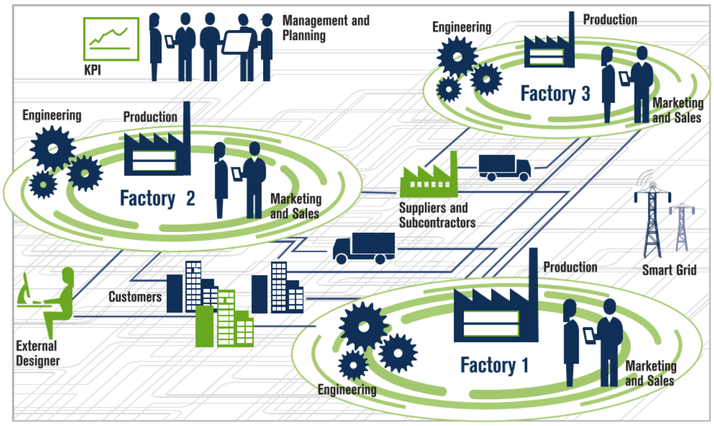


Figure 2.2: Horizontal integration through value networks [36]

This kind of horizontal integration of both customers and business partners can generate completely new business models and new models for cooperation, representing a challenge for all those involved. Legal issues and questions of liability and protection of intellectual property are becoming increasingly important [62].

2.3.2. End-to-end engineering across the entire value chain

Modelling plays a key role in managing the increasing complexity of technological systems. The appropriate IT systems should be deployed in order to provide end-to-end support to the entire value chain, from product development to manufacturing system engineering, production and service, shown in figure 2.3. A holistic systems engineering approach is required that spans the different technical disciplines. For this to be possible, engineers will need to receive the appropriate training.

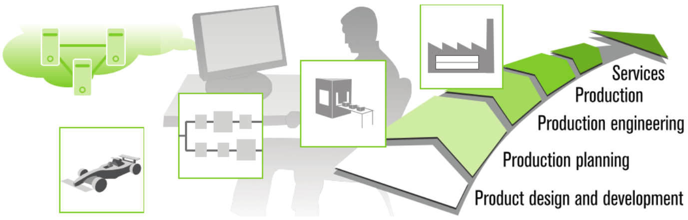


Figure 2.3: End-to-end engineering [36]

The model-based development enabled through CPS allows the deployment of an end-to-end, modelled, digital methodology that covers every aspect from custom- er requirements to product architecture and manufacture of the finished product. This enables all the inter-dependencies to be identified and depicted in an end-to-end engineering tool chain. The manufacturing system is developed in parallel based on the same paradigms, meaning that it always keeps pace with product development. As a result, it becomes feasible to manufacture individual products. It is possible to preserve the value of the current in- stalled base by migrating to this tool chain gradually over a number of stages.

2.3.3. Vertical integration and networked manufacturing systems

Vertical integration refers to the integration of the various IT systems at the different hierarchical levels (e.g. the actuator and sensor, control, production management, manufacturing and execution and corporate planning levels) in order to deliver an end-to-end solution.The setting for vertical integration is the factory. In tomorrow's smart factories, manufacturing structures will not be fixed and predefined. Instead, a set of IT configuration rules will be defined that can be used on a case-by-case basis to automatically build a specific structure for every situation, including all the associated requirements in terms of models, data, communication and algorithms. This structure can be seen in figure 2.4.

In order to deliver vertical integration, it is essential to ensure end-to-end digital integration of actuator and sensor signals across different levels. It will also be necessary to develop modulation and reuse strategies in order to enable ad hoc networking and re-configurable of manufacturing systems, together with the appropriate smart system capability descriptions. Moreover, foremen and operators will need to be trained to understand the impact of these approaches on the running and operation of the manufacturing system.

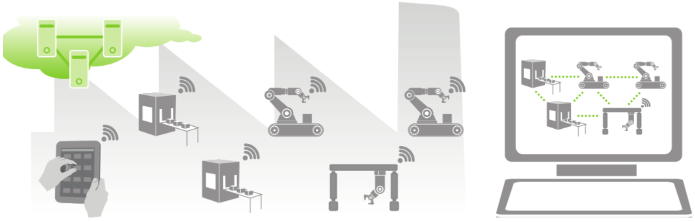


Figure 2.4: Vertical integration and networked manufacturing systems [36]

2.4. Examples

Below, two exampled are provided by Kagermann which show the difference after implementation of Industry 4.0 [36].

Example 1: Sudden change of supplier during production

Circumstances beyond the manufacturer's control, such as unexpected natural disasters or political crises, mean that they often have to change suppliers suddenly during production. Industry 4.0 can help to make these changes substantially smoother by running simulations of the affected downstream services, thus allowing different suppliers to be evaluated and the best alternative to be selected.

The current situation

In the event of unexpected supplier failure, it is currently difficult for manufacturers to assess the impact on current production and downstream processes and come up with a timely response. Sudden supplier failures result in significant additional costs and delays in production and thus entail major risks to companies' business. They need to take quick decisions about which alternative supplier to use as cover, how to execute the logistics for goods that are currently in production, how long current stocks are likely to last, which products already contain components from the failed supplier and whether the alternative suppliers actually have the ability and skills needed to provide the required capacity by the relevant deadline. Currently, it is only possible to provide partial IT support for these decisions.

The situation of tomorrow

In Industry 4.0 it will be possible to simulate all the steps in the manufacturing process and depict their influence on production. This will include simulation of inventory levels, transport and logistics, the ability to track the usage history of components that have already been used in production and provision of information relating to how long components can be kept before they expire. This will enable product-specific set-up costs to be calculated and reconfiguration of production resources to be kept to a minimum. It will also be possible to assess the relevant risks. It will thus be possible to simulate the different costs and margins of alternative suppliers, including simulation of the environmental impact associated with using one supplier over another. Extensive networking of manufacturing systems will make it possible to analyze alternative suppliers and their capacity in real time. It will be possible to contact and engage suppliers directly via the appropriate secure channels in the supplier cloud.

Example 2: Supporting custom manufacturing

The dynamic value chains of Industry 4.0 enable customer- and product-specific coordination of design, configuration, ordering, planning, production and logistics. This also provides the opportunity to incorporate last-minute requests for changes immediately prior to or even during production.

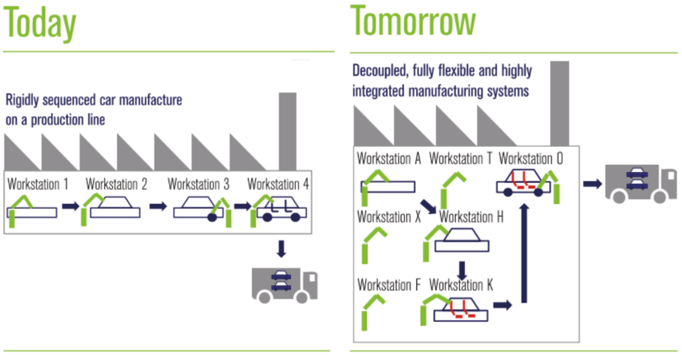


Figure 2.5: Supporting custom manufacturing [36]

The current situation

Today's automotive industry is characterized by static production lines with predefined sequences which are hard to reconfigure to make new product variants. Software-supported Manufacturing Execution Systems (MES) are normally designed with narrowly defined functionality based on the production line's hardware and are therefore equally static. The nature of employees' work is also determined by the production line's functionality and is thus usually very monotonous. Individuality is not encouraged. As a result, it is not possible to incorporate individual customer requests to include an element from another product group made by the same company, for example to fit a Volkswagen with Porsche seats.

The situation of tomorrow

Industry 4.0 results in the emergence of dynamic production lines. Vehicles become smart products that move autonomously through the assembly shop from one CPS-enabled processing module to another. The dynamic reconfiguration of production lines makes it possible to mix and match the equipment with which vehicles are fitted; furthermore, individual variations (e.g. fitting a seat from another vehicle series) can be implemented at any time in response to logistical issues (bottlenecks) without being constrained by centrally prescribed timings. It is simple to execute this type of reconfiguration and the cars move autonomously to the relevant workstation. The IT solution for MES now constitutes a central component from start to finish from design through to assembly and operation. The difference can be seen in figure 2.5.

2.5. Main challenge

The fourth industrial revolution- that is characterized by the increasing digitization and the interconnection of products, value chains and business models- requires a significant investment[17]. The journey towards implementing the Industry 4.0 vision will involve an evolutionary process that will progress at different rates in individual companies and sectors. Demonstration projects should therefore be developed and new products brought to market as soon as possible [36].

Companies PwC and Strategy& researched the integration of Industry 4.0 [39].The study made by the companies PwC and Strategy& in 2015 in the German sector of manufacturing and engineering, automotive and process industries, is based on surveys of 235 German companies. The respondents expected that regarding to the digital transition will lead to a significant transformation of their companies and they estimate that the share of investment will account for more than 50 % of the planned capital investments for the next 5 years. Therefore, the first and the main challenge is the investment that means to apply Industry 4.0 solutions.

Thus, the main challenges are the high investment levels and often the unclear business cases for the new industrial internet applications. As well as to have the sufficient skills to meet the needs of digital world. Moreover, binding standards must also be defined and tasks in the field of IT security have to be solved. It is clearly needed that companies, trade unions, associations and policy-makers cooperate in order to spread this fourth industrial revolution [17].

Implementation should be addressed through a dual strategy. Existing basic technologies and experience will need to be adapted to the requirements of manufacturing engineering and rolled out rapidly on a widespread basis. At the same time, it will also be necessary to research and develop innovative solutions for new manufacturing sites and new markets.

2.6. Conclusion

Industry 4.0 is an high-tech strategy devised in Germany. This strategy is constructed to adapt new technologies which have high influences on the manufacturing business. As Industry 4.0 is an industrial revolution is predicted a priory, it is expected to provide huge opportunities for companies and have enormous impact on the operational effectiveness and development.

The vision of Industry 4.0 is to create a ubiquitous connection between people, things and machines which is focused on creating smart products, procedures and processes. These smarts products and services main feature is to communicate and have knowledge to make accurate and deliberate decisions for the desired next step for production while taken into account the current state of all elements and the companies' business model.

There are four main components which enables the theory of Industry 4.0. CPS are systems which integrate physical processes into the cyberspace making it possible to digital follow the physical processes. IoT is a global network infrastructure accessible for an overall interconnection between all objects in which interoperable communication is possible. IoS is based on IoT and enables service vendors to offer their services via the internet making it possible to reach to consumers via various channels. Smart factories integrates the above components and is the system in which every component is interconnected, making it possible for products to find their way independently through production processes and are easily identifiable and locatable at any time, pursuing the idea of a cost-efficient, yet highly flexible and individualized mass production. Smart factories will make the increasing complexity of manufacturing processes manageable.

The key strategy is to create a connection between all components within one business with products that are designed completely for this use but also maintain an high co-operation between other businesses. Hereby, the main challenge is to acquire sufficient IT skills to rapidly implement the technologies on a widespread basis which is inseparable with high investments costs. The implementation of Industry 4.0 will result in an overall smoother operation measured by significant faster lead times, lower waiting times, less maintenance, more operation hours and a real-time adjustable operation.

In the next chapter, *The state of the art of Logistics 4.0*, the theory of Logistics 4.0 will be elaborated. This theory affects the same businesses but more specific on the logistics systems.

3

The state of the art of Logistics 4.0

In this chapter, a thoroughly description of the state of the art of Logistics 4.0 is provided. Firstly, the explicit terminology of logistics is described. Secondly, the vision and main components are elaborated, followed by examples and conclusions. During this chapter, several technologies will be described which influences the implementations of Logistics 4.0. These will be more explicit elaborated in the next chapter, *Technologies*.

In short, the objective of Industry 4.0 is to increase the digitization within a business by embedding smart objects into the digital and physical processes. The embedded smart objects result in a high-level of interconnection of products, value chains and business models which offer a new level of control. This new level of control makes it possible to constantly provide the best solution within the main objective of the company.

Logistics 4.0 is related to Industry 4.0 as logistics is related to industry. Logistics 4.0 is a narrower term which covers the logistics system of industry instead of the whole industry. However, both strive for the same objective and affect each other in this. The logistics system is refers to a specific part in the industry, explained in the next section, which has high input in the actual progress of a business. And in this chapter it will become clear what these certain parts of industry are and how they will be affected by Logistics 4.0.

3.1. The definition of logistics

Early references to logistics as a word are found preliminary in military applications. It is found in 1898 that logistics is discussed as, “Strategy is art of handling troops in the theatre of war; tactics that of handling them on the field of battle... The French have a third process, which they call logistics, the art of moving and quartering troops...” [45]. Nowadays, the term logistics means, in a broad sense, the process of managing and controlling the flows of goods, energy, information and other resources as facilities, services and people. It involves the integration of information, transportation, inventory, warehousing, material handling and packing [24].

Supply chain management is a term that emerged later from the textile industry and grocery industry, and it is used to define the integration of all inbound logistics processes with the outbound logistics, linking all of the partners in the chain including departments within an organization and external partners including suppliers, carriers, third party companies and information system providers [45]. Supply chain management and logistics are commonly entangled terms.

Therefore, we will refer in this thesis to the logistics management as the governance of supply chain functions and intralogistics functions, as an integrated logistics. Logistics management activities typically will include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function will also include customer service, sourcing and procurement, production planning and scheduling, packaging and assembly. It is part of all levels of planning and execution (strategic, operational and tactical) [72].

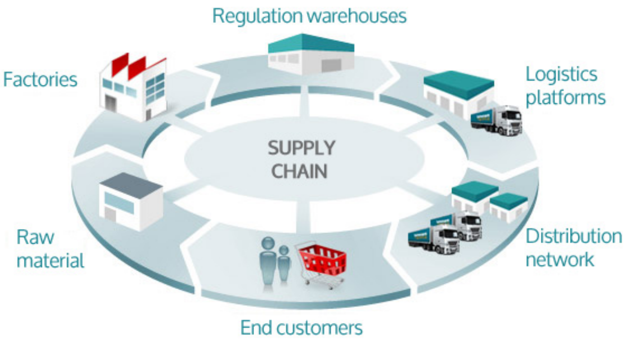


Figure 3.1: Logistic management (supply chain functions) [43]

As we can see in the figure 3.1, supply chain seen as integrated logistics, encompasses logistics inbound and the logistics outbound as well as all the management processes needed to distribute products and reach a proper delivery to customers (at the right moment, in the right place to the right customer)[17].

For industries, logistics helps to optimize the existing production and distribution processes based on the same resources through management techniques for promoting the efficiency and competitiveness of enterprises. The closely linked component of the logistics system are:[72]

1. **Logistics services**
   Logistics services support the movement of materials and products from inputs through production to consumers, as well as associated waste disposal and reverse flows. They include activities undertaken in-house by the users of the services (e.g. storage or inventory control at a manufacturer's plant) and the operations of external service providers. They comprise physical and nonphysical activities (e.g. transport, storage and supply chain design, selection of contractors, freight-age negotiations respectively).

2. **Information systems**
   Information systems include modelling and management of decision-making, but also issues such as tracking and tracing of a product. The information system provides essential data and consultation in each step of the interaction among logistics services and the target stations.

3. **Infrastructure**
   Infrastructure comprises human resources, financial resources, packaging materials, warehouses, transport and communications. Most fixed capital is for building those infrastructures. They are concrete foundations and basements within logistics systems.

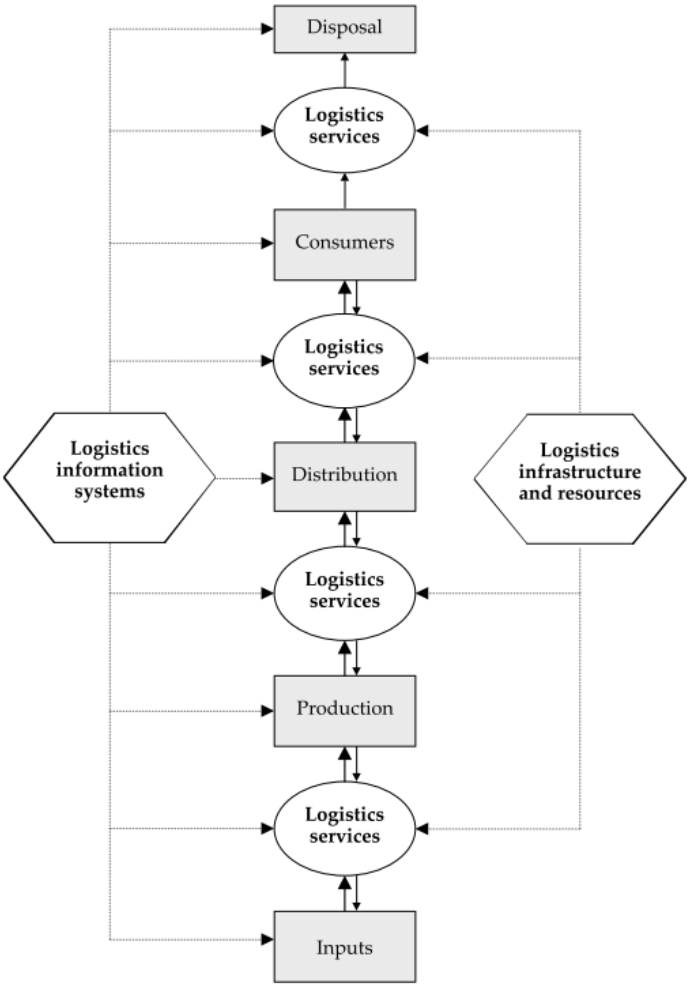


Figure 3.2: Overview of the logistics system [13]

As summarized in figure 3.2, it can be said that the logistics system involves the entire process of shipping raw materials (inputs); the conversion of the goods into the final products at the plant (production); the transportation of the products to different warehouse and eventually the delivery of these products to the final customers (distribution and consumers). To manage all this system efficiently, the transportation and the storage of the goods are essential points in order to control the dynamic and the static material flows [24].

3.2. The vision

Uckelmann describes the logistics [73]. Having the right product at the right time at the right place and in the right condition – these are the well-known requirements for logistics and transportation in general. But fulfilling these requirements is getting more and more complex in a dynamically changing logistic environment. There is a shift from traditional supply chains to open supply networks. Long-lasting business relationships are overrun by short-term business connections. The highly dynamic logistic markets and the advancing complexity of logistic networks require new methods, products and services. Aspects such as flexibility, adaptability and pro-activity gain importance and can only be achieved by integration of new technologies. These new technologies are utilized and adapted in the theory of Logistics 4.0.

These new technologies are smart products and smart services. Therefore, this integration of new technologies is often referred to as smart logistics. The definition of smart logistics will be subject to change dependant on the respective current technology developments. In this case, the term "smart" is thought to be misleading due to time dependency: The "Smart House" of 1935 had an electric light in every room. The "Smart House" of 1955 dared to put a TV and a telephone in every room. And the "Smart House" of 2005 will have computers in every room. These examples show that “Smart” is defined by deployment of innovative and commercially available state-of-the-art technology [73]. Due to this reason it is more accurate to refer to the term as Logistics 4.0.

As earlier stated, when the vision of Industry 4.0 was created, there was absence of a clear definition. An high-tech strategy was composed in which the essence of industry was described in combination with possible technologies but without an accurate definition. As a result, the vision was identified and implemented into a definition by individuals.

Logistics 4.0 can be approached, as stated by Szymanska, on two ways [71]. As regards to the short-term approach Logistics 4.0 is defined as firm and mutually related processes between independent members with the use of large amount of data. As to the medium-term approach Logistics 4.0 is defined as autonomous, self-organizing systems within other systems. The Logistics 4.0 definition combines two aspects: processual; supply chain processes are a subject of the Logistics 4.0 actions, and technical; tools and technologies that support internal processes in the supply chain.

Logistics 4.0 aims at enlarging the supply chain members' efficiency and performance. The supply chain is based on decentralized decision-making structures [18] Due to the similarities between the Logistics 4.0 and Industry 4.0 concepts, the former one is based on its typical features, i.a. digitalization, automatization, networking and mobility [70]. The Logistics 4.0 technological solutions are based on using drones, self-steering vehicles, sensors, Big Data, Global Positioning system (GPS), RFID and Machine-to-Machine (M2M) [71].

The definition of Logistics 4.0 is to adapt high-tech technologies into the logistics components to secure the vision of Industry 4.0. These technologies (smart products and services) create a connection between people, things and machines whereby they communicate and gain knowledge to accurately make decisions for the logistics services, information systems and infrastructure and resources to adapt to the desired business model. This definition is further explained within the vision in the next section.

The logistics 4.0 concept implementation advantages are: savings in human work, high standardization of linking logistic function to information pieces and the use of equipping logistics enterprises with the newest technologies. The disadvantages are: high investment cost and the IT supply network possession requirements [71].

3.3. Main components

The characteristics of Logistics 4.0, to keep pace with the swift evolution in the domain of manufacturing, is as follows: adaptability, changeability, flexibility, self-organization, quick re-configurable, autonomous behavior of single elements and intelligent decision making [25]. Those requirements can be met by embedding the following main components into the system [50]:

1. **Autonomous logistics.** Autonomous control describes processes of decentralized decision-making in hierarchical structures. In logistics systems, autonomous control is characterized by the ability of logistic objects to process information, to render and to execute decisions on their own.
2. **Product intelligence.** A physical order or product instance that is linked to information and rules governing the way it is intended to be stored, prepared or transported that enables the product to support or influence these operations.
3. **Intelligent transportation systems.** Intelligent transport systems aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks.
4. **Intelligent cargo.** A cargo-centric approach with cargo having capabilities such as self-identification, context detection, access to services, status monitoring and registering, independent behaviour and autonomous decision making.
5. **Self-organizing logistics.** A self-organizing logistics system can function without great intervention by managers, engineers, or software control. It is capable of making decisions while taking the future and the current situation into account.

These components together from an Intelligent Logistics System (ILS), also known as integrated intelligent logistics system but in this paper be referred to as ILS. An ILS covers all elements of Logistics 4.0. It is comparable with Industry 4.0 creating smart factories which embeds all characterizations of the strategy.

3.4. The strategy

The strategy of Logistics 4.0 is equal to the strategy of Industry 4.0. The implementation of Industry 4.0 should aim to leverage the market potential for the manufacturing industry through the adoption of a dual strategy comprising the deployment of CPS in manufacturing on the one hand and the marketing of CPS technology and products in other to strengthen the logistics system. The key is to find extra fertile solution within the combination of physical technologies and IT. Hereby, the same three key features as Industry 4.0 must be incorporated: [36]

- Horizontal integration through value network
- Vertical integration and networking manufacturing systems
- End-to-end engineering across the entire value chain

Hereby, it is necessary to implement an hierarchical structure. Such structure provides a logical order in which higher placed elements have more authority. This structure is in line with the strategy elements: *Vertical integration and networking manufacturing systems* and *End-to-end engineering across the entire value chain*. The vertical integration is reflected between all components of the system and the end-to-end engineering can be seen within the smart products. It is necessary to have a hierarchical structure to successfully operate autonomous orders between products.

The other key feature of the strategy of Industry 4.0, *Horizontal integration through value network*, is more difficult to achieve within the logistics of a business. Horizontal integration is the communication between different logistics systems. This can be achieved by having data-transfer between the logistics systems whereby the operation system must have equal parts for the interconnectivity to be possible. Most likely, this is the case with one company with multiple logistics systems but it becomes less obvious between different businesses.

This strategy is integrated into the implementation in Chapter 5. This chapter provides the structure of the elements inside the ILS while maintaining the key features of the strategy.

3.5. Negative aspects

- The information gap between current knowledge of companies and the desired knowledge for Logistics 4.0 can influence the state of different companies resulting into larger, more successful companies to grow exponential while smaller companies cannot compete in this race due to the

3.6. Conclusion

Logistics 4.0 is a more specific term than Industry 4.0, as it specifies on the logistics systems of a business while Industry 4.0 takes the whole into account. The vision of Logistics 4.0 is to enlarge the efficiency and performance of a logistics systems by adapting high-tech technologies. This will result into an ILS, instead of a smart factory for Industry 4.0, which creates an interconnection between all elements within the system with the use of CPS, IoT and IoS. The ILS is a logistics system in which real-time data-transfer, communication and predictions of the future for the whole system is possible. This results into a system which can operate autonomously by making decentralized decisions while taking into account the current status of all elements in the system, business model of the company, connection with business partners and the predicted future.

This vision can be achieved by improving the component of the logistics system. The main components of a logistics system which is fully integrated with the theory of Logistics 4.0 are autonomous logistics, product intelligence, intelligent transportation systems, intelligent cargo and self-organizing logistics.

Hereby, the strategy to achieve the objectives of Logistics 4.0 is equal to Industry 4.0: to create a connection between all components within the logistics system with products which are end-to-end designed for this function while maintain a high co-operation with logistics systems from other businesses.

The next chapter, *Technologies*, elaborates the technologies supporting the vision of Logistics 4.0. These technologies provide more tangible concepts to achieve Logistics 4.0.

4

Technologies

This chapter discusses the technological foundation of Logistics 4.0. Firstly, after a short introduction, the main components are elaborated by their basic technologies, functionality, interaction with the environment and the degree of influence on the system. Secondly, smart objects are discussed as a representative of the main components. Herein, there is differentiated between hardware and software elements. Thirdly, several tangible examples of these technologies are provided and all the above are finalized in a conclusion.

In short, the objective of Logistics 4.0 is to enlarge the efficiency and performance of the logistics system by increasing the independency, flexibility and controllability of the system. This can be achieved by creating an ILS which embeds the main components and characteristics of Logistics 4.0..

It has to be pointed out that behind the theory of Logistics 4.0, there is not such thing as one explicit technology. It is more the continuous progress of information and communication technology in combination with an exponential growth of computing, transmission, and storage capacity, which enables the emergence of increasingly powerful, interconnected new technological systems[9]

The technologies described in this chapter are based on the thesis *The concept of Industry 4.0* written by Bartodziej (2017). An extended survey has been made during this thesis resulting in the following sections. [9]

4.1. Main components of Logistics 4.0

As determined in the previous chapters, the main components of Logistics 4.0 are CPS, IoS, IoT and ILS. These technologies are earlier discussed but due to their key presence in the theory of Industry 4.0 and Logistics 4.0 must be elaborated more.

4.1.1. Cyber-Physical Systems

CPS are defined as the systems which offer integration of computation, networking, and physical processes or in other words, as the systems where physical and software components are deeply intertwined, each operating on different spatial and temporal scales,exhibiting multiple and distinct behavioral modalities, and interacting with each other in a myriad of ways that change with context[38]

The coupling of information processing components and physical objects in automation is not new and already existed since the 1970s. The essential innovation, which comes along with CPS, is the interconnection of objects and processes via open and global information networks – via the internet[8] The main technological driver for the emergence of CPS has hardware and software based origins. On the one hand, the technological infrastructure consistent of embedded systems and high-performance sensors, actuators, and communication interfaces provides the inevitable hardware capacities. On the other hand, the use of the business web, integration platforms, and services based on cloud solutions opens entirely new business opportunities[12]

With special regards to the last two definitions, it is interesting to notice, that not only embodied objects (systems) can constitute CPS but rather intangibles such as operational and managerial processes as well. Due to this fact, CPS still constitute a rather abstract, theoretical concept more than a finished technology, which is ready to use and already has found its first applications and prototypes in industrial practice. Another characteristic, which can be used to describe a CPS and, simultaneously, shows the diverse dimensions of these systems, is the degree of decentralization of their structure and their spatial volume. By means of advanced micro-system technologies, a CPS can be placed on a single microchip including various sensors and a microprocessor for processing data. A bigger CPS can be constructed in the form of an entire machine tool, which can be in turn a part of an even greater CPS – a whole factory. An extreme manifestation of a CPS would be its allocation in a worldwide network, e.g. a worldwide operating company[9] Geisberger and Broy (2015) describe five essential dimensions of CPS, which build upon each other towards increasing openness, complexity, and smartness:[12]

1. Merging of the physical and virtual worlds

2. Systems of Systems with dynamically adaptive system boundaries

3. Context-adaptive systems with autonomous systems; Active real-time control

4. Cooperative systems with distributed and changing control

5. Extensive human-system cooperation

4.1.2. Internet of Things

The Internet of Things (IoT) is an emerging global Internet-based information architecture facilitating the exchange of goods and services. The IoT has the purpose of providing an IT-infrastructure facilitating the exchange of “things” in a secure and reliable manner, i.e. its function is to overcome the gap between objects in the physical world and their representation in information systems. The IoT will serve to increase transparency and enhance the efficiency of global supply chain networks[79]

Haller et al defines the IoT as “a world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these ’smart objects’ over the internet, query their state and any information associated with them, taking into account security and privacy issues.” [28]

Extending the initial application scope, the IoT might also serve as backbone for ubiquitous computing, enabling smart environments to recognize and identify objects, and retrieve information from the Internet to facilitate their adaptive functionality. [79]

An integration of multiple CPSs has an ubiquitous connection with IoT due to their high level of integrated cyber processes. The key element of CPS which is to have digital information of the current physical state of a system provides the ideal basis for IoT to control multiple CPS. The aim of business with CPS is to have a decentralized control which is perfectly maintainable with IoT. IoT can maintain a large scale of operating CPS while taking into account the overall preferences of the whole.

4.1.3. Internet of Services

IoS is strongly related to IoT based on the IoT and the idea that services are made easily available through web technologies, allowing companies and private users to combine, create and offer new kind of value-added services.

Taking this into account, the vision of the IoS is to enable service vendors to offer their services via the internet. Depending on the possible degree of digitalization services can be offered and demanded worldwide. The IoS consists of participants, an infrastructure for services, business models and the services themselves. Services are offered and combined into value-added services by various suppliers; they are communicated to users as well as consumers and are accessed by them via various channels[14]

Where IoT enables the ubiquitous connection between objects, IoS takes it a step further by providing services to third parties. This is based on the same technology but offers an extra functionality which is known to be preferable in the current "service society".

4.1.4. Intelligent Logistics System

The ILS is the actual system of a business where the logistics systems runs with the characteristics of Logistics 4.0. It is the umbrella technology where all the other main components are operating in. The ILS is the system of CPS (i.e. smart objects) which are cyber-connected with each other based on IoT and IoS. ILS can be seen as the intelligent technology for the logistics system which provides the interconnection between all elements. A proper designed ILS runs the logistics of a business without intervention of employees within the limits of the exceptional boundaries. The true innovative power of smart object comes from their interconnection.

Intelligent systems have their origin in cybernetics. Cybernetics one of the fundamental concepts of control and regulation of complex, hybrid systems by analyzing the structures, relations and behavior. The innovative idea of cybernetics was to refuse to set any requirements on the type of systems which ought to be controlled. Cybernetics was the first approach to transfer the knowledge from classical control and regulation technology to heterogeneous technical systems[35]

Hence, an ILS integrates the smart objects and demonstrates through the interaction of these smart objects a kind of intelligent behavior. These systems of smart objects can process data and information. This ability can be either implemented centralized or decentralized within the smart objects itself. It also can be installed in a centralized structure such as a central computer. A geographic distribution of smart objects enables totally new functionalities within the interconnected systems[9]

4.1.5. Conclusion of the main technologies

The previous explanations of the main components of Logistics 4.0 show that the technologies and terminology overlap. Simple stated, the technology of IoT and IoS is embedded in CPS while CPS are the embodiment of ILS. However, the main components clearly shows the foundation of Logistics 4.0 - the interconnection of every component in the system which enables autonomous actions and decentralized decision-making.

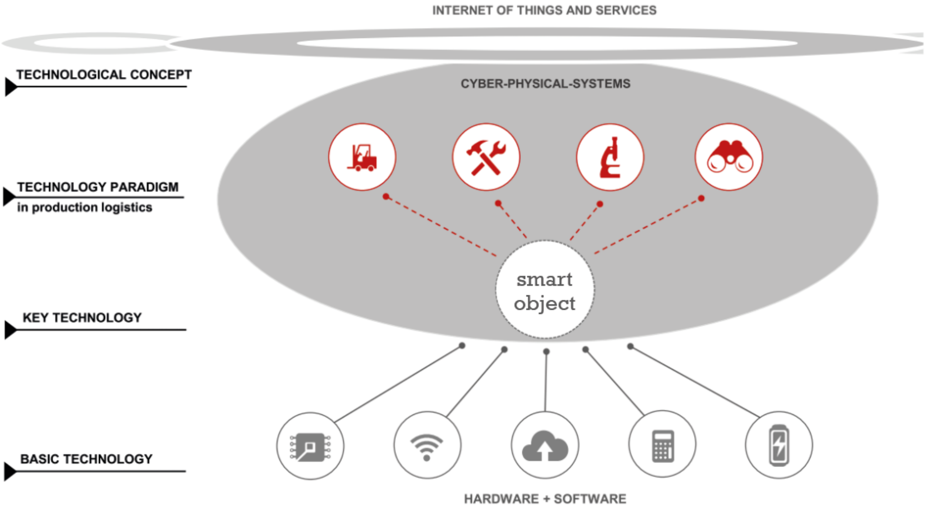


Figure 4.1: Hierarchical structure of technologies within the concept Logistics 4.0 [9]

The structure of the main components, illustrated in figure 4.1, shows the overlap in which the smart object is the central technology which embeds CPS, IoT and IoS. The ILS is the construction of multiple smart objects in the logistics system. As can be concluded, the smart object is the key technology to enable the objectives of Logistics 4.0 which is comprehensively elaborated in the next section.

4.2. Smart objects as representative of main components Logistics 4.0

The smart objects in production logistics is considered as the practical reflection of the abstract technological concepts above. Considering the fact that CPS, IoS, IoT and ILS are abstract, theoretical and yet intangible technological concepts, which based on the opinion of Industry 4.0 and Logistics 4.0 can be developed and implemented in diverse designs, the evolution of smart objects is perceived to have already a bigger practical relevance [9].

The perception of smart objects, described by Windt [82], is that the independent evolution of intelligence necessarily requires the existence of a body (object), which can interact with its environment and consequently, generate knowledge by experiences. Intelligence, therefore, is an expression of sensormotoric coordination, which means that sensors (sensory organs) and actuators (motors, muscles) are coordinated by intern information processing procedures.

For the realization of smart objects, there are various technologies available. These technologies often are called “enabling technologies” as they are perceived as a technological enabler for the innovative application of smart objects [10]. The basic technologies which enable the functions of smart object are discussed in the following section. Hereby, there is differentiated between hardware and software based technologies. Both offer essential possibilities for optimization of smart objects.

4.2.1. Hardware-based technologies and functions of smart objects

Bartodziejs states that basic technologies enable the functions of smart objects [9]. These technologies are going to be presented in this chapter with special regards to their enabling mechanisms - their functions. The selection of technologies makes no claims to completeness; instead, it is the result of an extensive literature review on the functions of smart objects in production logistics.

Automatic identification and localization

According to DIN standard 6763, “identification” includes a “[...] unique and unmistakable recognition of an object based on essential characteristics with a predefined accuracy with regards to the targeted purpose.”[6]. An automatic identification, in fact, is the connective link between the flow of material and the flow of information in where the physical and virtual world is “meld” together. There are several concepts concerning the technological configuration of the identification procedure, which based on the particular requirements of an application, can be designed correspondingly. Nowadays in manufacturing industry, automatic identification using automatic identification technologies (Auto-ID) has prevailed [31]. The framework of smart objects defines three major dimensions of Auto-ID technologies, which include optical identification and radio identification [15].

The optical identification mostly includes the use of barcode systems. Those systems are the worldwide standard for automatic identification and, therefore, perceived as the most important Auto-ID technology. The disadvantages of barcode systems are a slow information flow since bar codes are a line-of-sight technology that requires manual scanning and only allows one item to be read at a time [51].

The new technology of identification technology, RFID, is summarized by Weinstein [80]. RFID disables the disadvantage of sight. The basic premise behind RFID systems is that you mark items with tags. These tags contain transponders that emit messages readable by specialized RFID readers. A reader retrieves information about the ID number from a database, and acts upon it accordingly. RFID tags can also contain writable memory, which can store information for transfer to various RFID readers in different locations. This information can track the movement of the tagged item, making that information available to each reader.

RFID tags fall into two general categories, active and passive, depending on their source of electrical power. Active RFID tags contain their own power source resulting in a stronger transmitted signal and a further accessible distance. The power source makes them larger and more expensive, so mostly used on large items tracked over long distance. Because of their on-board power source, active tags operate at higher frequencies - commonly 455 MHz, 2.45 GHz, or 5.8 GHz - depending on the application’s read range and memory requirements. Readers can communicate with active RFID tags across 20 to 100 meters.

Passive tags, on the other hand, are very inexpensive and therefor will likely be the basis of most of the growth in RFID implementations. Their costs correlate with their characteristics, currently being passive RFID tags contain about 2 Kbits of memory. This is too small to hold much more complex information than identification and history information. The technology behind RFID is constantly improving, so the amount of information and capabilities of RFID tags will increase over time, allowing RFID tags to eventually contain and transmit much more information. A passive tag reader constantly broadcast its signal and receives an electromagnetic signal when the tag is in reach. Passive tags typically operate at frequencies of 128 KHz,13.6 MHz,915 MHz, or 2.45 GHz, and have read ranges of a few inches to 30 feet. Frequency choice depends on the system’s environment, what material the signal must travel through, and the system’s required read range.

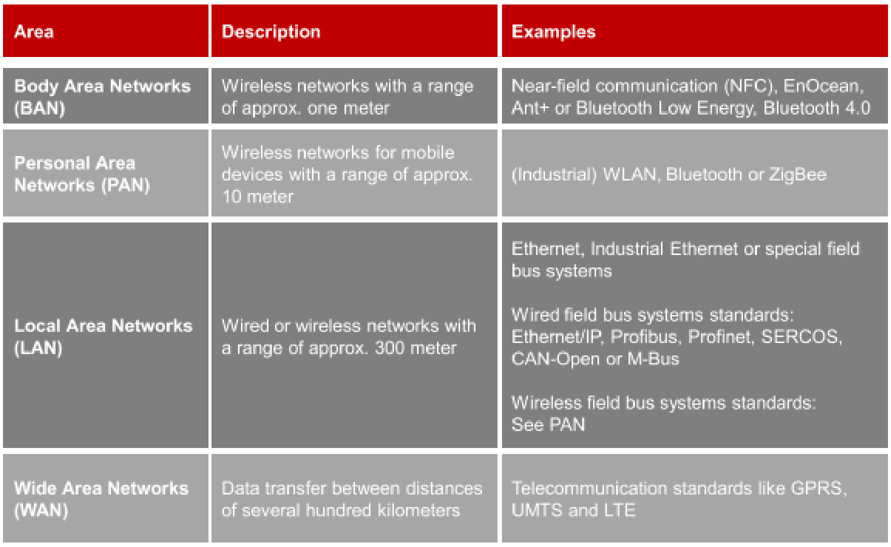
For example, when in use in an outside terminal port, the signal must work with different conditions such as a small layer of ice or multiple centimeters of snow.

Next to the transmission of a unique identification number, other information might additionally be saved and exchanged with other systems, stated by Bartodziej [9]. The data-on-chip principle allows to save data on, for example in logistics systems, transport destination, content and geometrical form. It, furthermore, allows equipping physical objects with a digital product memory, which can be used to either ensure a complete trace-ability of objects or optimize manufacturing processes, while providing information on historical production data and further production steps. A further application of RFID is the determination of a physical objects' position within a factory, so to speak the localization. Transport systems can be equipped with reading devices to read embedded RFID transponders on the floor of the factory. Hence, AGVs could be traced within a predetermined radius of movement at any time. To continue this thought strictly, materials that are transported by an AGV could also be localized at any time, as they are in the range of the AGVs' readers (given the fact that the material also has RFID transponders).

Machine-to-machine communication

The ability of smart objects to communicate, in literature and in practice, is next to the explained functions in the previous chapter considered an integral technology of the IoT and IoS. Dorst & Scheibe describe, within their elaborations on an implementation strategy for Industry 4.0 component, an architecture model which explicitly deals with components have to communicate passively with the network [75]. However, a more advanced capability of communication, the so-called active communication, describes the communication between smart objects. This form is the common knows as M2M communication [9].

The classical automation technology within the fourth industrial revolution will be heavily influenced by communications technology that is currently leading the private consumer market. Communication interfaces can be differentiated by their operating range and physical installation, which includes either a wired or wireless communication. Figure 4.2 presents the different types of communication technologies within the industrial environment which are currently in use.



Area	Description	Examples
Body Area Networks (BAN)	Wireless networks with a range of approx. one meter	Near-field communication (NFC), EnOcean, Ant+ or Bluetooth Low Energy, Bluetooth 4.0
Personal Area Networks (PAN)	Wireless networks for mobile devices with a range of approx. 10 meter	(Industrial) WLAN, Bluetooth or ZigBee
Local Area Networks (LAN)	Wired or wireless networks with a range of approx. 300 meter	Ethernet, Industrial Ethernet or special field bus systems Wired field bus systems standards: Ethernet/IP, Profibus, Profinet, SERCOS, CAN-Open or M-Bus Wireless field bus systems standards: See PAN
Wide Area Networks (WAN)	Data transfer between distances of several hundred kilometers	Telecommunication standards like GPRS, UMTS and LTE

Figure 4.2: Industrial communication technologies [9]

Bartodziej describes the complete end-to-end integration within the ILS [9], where M2M does not only mean communication between different field devices on the shop floor (as the name suggests) but also among various IT systems on various levels within a company. For this, a unique communication standard has to be implemented, which is currently a major challenge due to the variety of manufacturer-specific standards. The communication protocol OPC Unified Architecture (OPC-UA), jointly created by 470 manufacturers of the OPC Foundation in the last years, developed to an accepted protocol family within the field of CPS technology. OPC-UA can be implemented to ensure horizontal as well as vertical communication within a factory, as long as there are no real-time critical requirements. For these so-called real-time requirements, classical field bus systems based on Ethernet solutions are more suitable and reliable. Thus, the OPC-UA protocol family can be used in combination with modern field bus systems as an essential connective link between MES and manufacturing level. A great benefit of this kind of protocol family is its scalability and interoperability. In the automation industry, OPC-UA can be used for data and information exchange independent of manufacturer, operating system, hierarchy, and topology. As a result, OPC-UA can be applied at all levels of the previously presented automation pyramid, from the smallest, energy efficient sensor over embedded field devices and gateways to operating panels, remote-control solutions within the production, mobile devices and tablets as well as on MES and enterprise resource planning level. OPC-UA has the potential to establish itself as a standard for data and information exchange for non-real time critical applications within the concept Industry 4.0, as it is perceived to be impossible to define an entirely new communication standard. Concerning the transportation protocol of M2M communication, the benefits of the use of Internet Protocol (IP) architecture is discussed in comparison to traditional gateways. An IP-based architecture of smart objects is interoperable across devices and communication technologies, evolving, and versatile while stable, scalable, and manageable, and simple enough that a resource-constrained smart object can easily run it while gateways have an inherent complexity and lack of flexibility and scalability.

Energy supply

Smart objects fulfill various functions by courtesy of their technological means. These objects require energy to carry out processes and tasks they are intended for. Smart objects gather demanded energy either from external sources or by generating it autonomously. Usually, the complexity of tasks is proportional to energy consumption. Therefore, the more energy the objects obtain, the more complex the functions they execute become[30].

According to Herzog, the energy supply for smart objects is the restraining factor for the practical use. The main reason that this is the restraining factor is due to the capacity of mobile batteries, the capacity increases significant slower relative to the demanded energy of smart objects [31]. There are three main possibilities to supply energy for smart objects: wired energy supply, inductive energy supply and internal energy supply [15]. Wired energy supply can only be applied to stationary smart object. Hereby, there is no issue in demand for energy and therefor not elaborated. Inductive energy can be supplied with RFID systems. The necessary energy for operating the RFID chip and communication is transmitted by the reading or writing device. Active transponders have a battery and, thus, can supply themselves with energy [31]. This is already the first initiative for internal energy supply which is the most promising concept. Energy self-sufficient smart objects generate the required energy from its environment without using any additional energy source [81]. This technology is called energy harvesting. There are several approaches to use natural energy from the environment based on, for example, thermoelectric sources, piezoelectric generators, or solar energy sources (photovoltaic) [49]. The most famous form that already has several applications in productive systems is the solar energy harvesting, which, for example, is used in logistics to track containers [81]. As solar energy in most cases only makes sense outside factory buildings, thermoelectric harvesting is perceived to have enormous potential in manufacturing environments. A thermogenerator module is employed to harvest energy from temperature gradients between a heat source and other natural sources [48].

Sensing and actuating

Smart objects must be capable of scanning their direct environment and, if necessary, must be able to react to changes in this environment. This part of the smart object can be achieved with sensors and actuators. Sensors collect the necessary data from its environment. Sensors and related measuring systems provide the essential, directly measurable information for mechatronic systems. Thus, they are important connective links between processes and information processing parts. In this context, the most relevant sensors are the ones, which collect mechanical or thermal measures and create an electric measuring signal [9].

Classical sensors serve as a first element of a whole measuring chain. This chain includes fundamental measuring processes such as the collection of measuring variables, processing of signals, processing of signals, signal amplification and analog-digital conversion [34]. Classical sensors simply collect measuring variables and transform them into an electrical signal. Whereas newer generations of smart sensors have the ability to transform collected signals into digital data and process it into valuable information. In other words, they can cover the whole measuring chain [32]. Smart sensors can also dispose a communication interface to interact with other smart sensors. In combination with an embedded microprocessor, these systems are called Micro Electromechanical Systems (MEMS) and are considered an own CPS [44].

This technological progress of sensing technologies evolves a new form of data collection, namely using wireless sensor networks which is described by Bartodziej [9]. The concept of wireless sensor networks is similar to that of smart objects, and much of the development in smart objects has occurred in communities dealing with wireless sensor networks. Wireless sensor networks are composed of small nodes that autonomously configure themselves into networks through which sensor readings can be transported. By using sensor networks, it will be able to make accurate observations on real world scenarios in various sectors. Wireless sensor networks open entirely new opportunities for the collection of context-specific information of smart objects. Context is defined as the quantity of information that is needed for the characterization of a situation, people and objects which is relevant for the interaction between a user and an IT application. Context-sensitive systems enable an application-specific use of context information as well as the adaption of behavior to the identified situation. Technological developments that can contribute to a practical solution are sensor fusion, meaning fusion of data from several different sensors, which are based on the above-explained sensor networks as well as pattern recognition, which is a characteristic of the optical measuring variable.

Actuators, summarized by Bartodziej [9], influence technical processes using a final control element, which can change certain process parameters. They are an essential part, just as sensors, within a mechatronic system. The type of actuator strongly depends on the purpose of its implementation. The mode of action of actuating systems is the same. The actuator receives an electrical signal (information) of a control unit and transfers it to an energy-adjusting element. The energy for the manipulation of physical processes is provided by the auxiliary energy element. Auxiliary energy can be transmitted in different forms; most common are thermal energy sources, chemical energy sources, fluid-based energy sources and electrical energy sources. Auxiliary energy is doing the actual work of an actuator. Hence, it is also called actuating or adjustment energy.

Data and information processing

The previous sections explained data generating and exchanging functions and technologies. To make efficient use of the collected data, additional technological components are required to process data [81]. The function of data and information processing can be implemented, based on the location of the processing procedure, in three ways: on the outside on a smart object, embedded inside a smart object and a combinations of the both. The processing of data and information outside an smart objects requires real-time capable communication interfaces embedded in a physical object. Sensors collect data and transfer it to a central IT system, where the actual processing procedure takes places. In some applications, data from various sources can be aggregated, transformed into information, and transferred back to an smart objects. Decentralized data and information processing requires directly embedded processing qualities on the smart objects [15]. The objective of data and information processing, independently of the location of the processing procedure, is to prepare information in such a manner that decision-making processes are optimally supported. To which degree information is processed strongly depends on the application itself [64]. The technological implementation of local data and information processing is realized by microcontrollers. A microcontroller is a microprocessor with built-in memory, timers, and hardware for connecting external devices such as sensors, actuators, and communication devices. Microcontrollers have two types of memory: Read-Only Memory (ROM) and Random Access Memory (RAM). ROM is used to store the program code that encodes the behavior of the device and RAM is used for temporary data the software needs to do its task. The purpose of a microcontroller is to run its software programs. The software is stored in the ROM and is typically already on the microcontroller when the device is manufactured [34]. These small computers are also known as embedded systems if they are embedded in something other than a computer. The primary difference between a traditional embedded system and smart objects is that communication is typically not considered a central function for embedded systems, whereas communication is an elementary characteristic for smart objects [74].

Human-machine interaction

Despite the increasing number of smart objects within future factories, numerous decisions will still be made by people. Thus, the interaction of smart objects has to go beyond the communication with other smart objects and IT systems. Smart objects interact with its users via Human-Machine-Interfaces (HMI). Input devices transfer user's actions in digital language, whereas output devices are used to represent computing language in a comprehensible way for the user. HMI are integrative parts of hardware and software components, which make information and control elements available to support the user [44]. For HMI nowadays, there are many technologies on the market. Some of them have already proven their practical relevance in everyday use. Considering voice control and gestures, for example, are a beneficial technology to interact with your smart object. Classical touchscreens are perceived to be the most important form of HMI input devices in future. New technologies enable the usage of a touchscreen even in abrasive, industrial environments. The technologies especially have an additional value in manufacturing, when they are used as personalized assistance systems, providing users context-sensitive information. Within these systems, not only information will be supplied but also recommendations on decision-making based on previously aggregated data. A characteristic feature of an advanced HMI output device is a comprehensible visualization of the information [27]. Currently, normal displays are used as output device. To achieve greater efficiency, it will be necessary for smart objects to recognize users' intentions and plans and anticipate human behavior. Hence, smart objects would show human awareness. Technologies such as user and human modeling enable the diagnosis, simulation, prediction, and support of human behavior in interactions with smart objects [9].

4.2.2. Software-based technologies and functions of smart objects

The software-based technologies provide different and smart solution for the optimization of smart objects and are summarized by Bartodziej [9]. These technologies also enable functionalities for smart objects but are less obvious for the user due their elusive concepts.

Artificial intelligence (AI)

AI describes the transmission from an object to an intelligent object (i.e. smart object) based on Information and Communication Technology (ICT). Hereby, it is essential for an object to make autonomous decisions and actions. Currently, people can have an anxious opinion regarding AI as they relate it to fear of "robots" to take over the world. However, a more (logistic) professional insight states that it enables technologies which will optimize business trajectories due to the autonomous decision-making followed by actions. Elaine Rich defines AI as the study of how to make computers do things at which, at the moment, people are better. Ertel claims the relevance of this statement while emphasizing that humans can always make optimal decisions and plans of action based on experience while computers can compute faster calculations but will be overclassed by humans due to their experience. [19]. In essence, there are five capabilities for the description of AI: rational acting, logical reasoning, cognitive behaviour, emergence and decision-making ability. These capabilities combined, describe human beings' ability to learn and solve problems. Consequently, a translation of this combination into a software-based program can be interpreted as AI[11].

A distributed AI can emerge using cooperation of spatially distributed technical systems. To achieve such an artificial intelligence within a system, the individual objects to a certain degree have to be intelligent. This meets the requirements for the theory of embodiment so that it can be concluded that the combination of software-related functions of AI and previously in detail described hardware-based functions of intelligence, constitute the whole range of intelligence for physical objects and systems.

Autonomy of action

The system has to have a certain autonomy of action to decide whether an action have to be made or not. This decision-making ability can be actualized by a software agent. Wong defines a software agent as "[...] distinct software process, which can reason independently, and can react to change, induced upon it by other agents and its environment, and is able to cooperate with other agents."[83] .There are six characteristics, which describe a software agent [60]:

1. Situated: Existence within an environment
2. Reactive: Adaptation of behavior to information of the environment
3. Autonomous: Possession of a certain degree of an autonomy of action
4. Social: Ability to cooperate with other agents
5. Rational: Execution of actions to fulfill an objective
6. Anthropomorphic: Representation of mental concepts of human beings

Based on these characteristics, four different types of agents can be defined, which increase in intelligence with each stage [60]:

1. **Simple reflex agent**: Choice of action based on actual perceptions without considerations of previous perceptions.

2. **Model-based reflex agent**: Choice of action based on a model of the environment and past additional perceptions. Model-based reflex agents can react to unexpected situations based on earlier experiences and perceptions.

3. **Goal-based agent**: Choice of action based on actual and past perceptions, and a desirable state.

4. **Value-based agent**: Choice of action based on the optimal solution to fulfill a desirable state.

Software agents can be implemented into physical objects to simplify the connection of new objects. These agents enable, dependent on the usage, a decentralized and (partially) autonomous behavior of smart objects based on self-control functions. The self-control of smart objects describes the process of decentralized decision making in heterarchic structures. Thus, it requires the ability of smart objects to make autonomous decisions in non-deterministic systems according to predetermined goals. Predetermined goals are essential to the existence and success fulfillment of self- controlled process. Essential characteristics for self-control of smart objects, according to Windt, are: autonomous, goal-oriented behavior, ability for autonomous decision-making, ability for measuring, back coupling and evaluation of events, ability for interaction, heterarchy and non-deterministic [82].

Schulz-Schäfer very explicitly investigates the autonomy of smart objects. He divides autonomy into three dimensions. Based on the degree of autonomy of each dimension, an increasing form of self-control is possible to realize. The dimensions are [65]:

- **Behavior autonomy**: the ability to execute predefined behavior programs.

- **Decision-making autonomy**: The ability to choose between different behavior programs.

- **Information autonomy**: The ability to generate new behavior programs based on new information.

The characteristics of self-controlling smart objects can be implemented with the different, previously mentioned types of software agent programs. It strongly depends on how much autonomy of action and, subsequently, artificial intelligence is supposed to be decentralized considering the objective of an application. For an efficient use of software agents within a system, multi-agent systems (MAS) can be implemented. In MAS, software agents cooperate and negotiate with other agents [23]. In MAS, the cooperation among agents is a decisive aspect, which generates new benefits based on the interaction of agents. In organization theory, coordination describes the mutual agreement of individuals among a system to serve a superior system goal [15]. Self-organization of a system is characterized by its ability to solve complex problems based on a collective procedure [11]. Agents harmonize their actions with each other so that a problem is strategically tackled and solved in a jointly coordinated manner. The problem-solving process is divided into three phases: problem decomposition, solving of sub-problems, and fusion of partial solutions [60]. In MAS, ontology is inevitable for a successful operation and efficient functionality. Ontology includes a predetermined vocabulary for the communication between agents. Without this and a subsequent semantic connection of the vocabulary, meaningful communication cannot take place [42].

Advanced data analytics

The expected data is to increase proportionally with the use of smart objects. This phenomenon is called big data. In future, the transformation of big data into valuable smart data will be a main challenge, which in the end increases the efficiency of processes when it is used appropriately [37]. The automated recognition of relations, meanings, and patterns using advanced data analytics technologies, can generate additional benefit [46]. These software-based technologies range from data mining methods to complex machine learning programs. Data mining tools enable, for example, the generation of new application and context-specific information using data aggregation from different sources. The analyzing algorithms depend on the problem to be solved. Data mining methods have to be implemented use case specifically[59] The next evolutionary step, based on advanced analytic methods, is self-optimizing ILS. Smart objects of such a system are equipped with cognitive skills. Based on machine learning technologies, historical data can be used to make a decision based on experiences. Thus, smart objects would have the ability to optimize their behavior [26]. Self-optimizing systems, as well as self-controlling and self-organizing systems, have superior system goals. In manufacturing processes, examples of these goals are reduction of lead time, reduction of energy consumption or increase of quality [21]. Hence, cognitive, self-optimizing systems have abilities that go beyond the previous mentioned control and organizing activities. Self-optimizing systems can fulfill complex planning tasks for a longer period [26].

Digital integration platforms

The objective of an end-to-end digital integration within an ILS can be facilitated by the use of so-called smart services on digital integration platforms. The integration of smart objects via IoT and IoS enables the field data level to be accessed from any location. An integration platform includes hardware, software, and communication systems. Kagermann defines integrative CPS platforms as federated units. Federally, in this context, means that services and applications can be used by different participants together for cooperative activities [36]. On these platforms, smart objects can both offer services and make use of services depending on individual needs [20]. A special application of a digital integration platform in manufacturing is a technology data marketplace. It occurs as an intermediary between demand and supply sides of digital data and provides only the necessary transparency for all types of security. Consequently, the original functionalities of smart objects can be extended by the temporary use of particular services. Based on the requirements for the hardware of such digital integration platforms, cloud- computing approaches, which have already proven their efficiency in practice, are considered a meaningful solution [22]. Cloud computing is characterized by scalability, high availability, fast network connection and thus, the provision of functionality using defined interfaces a fundamental technology for implementing Industry 4.0 scenarios [20].

In cloud systems, data from manufacturing processes runs together on a server, is analyzed, and goes back to its destination. Apple's Siri is an example of this functionality. A voice command is recorded through the microphone, the sound file is sent a server, where it is evaluated, and the result is transmitted as a control command to the sender unit [76]. These functions can be offered as services on digital platforms based on cloud systems. It is even conceivable that these services will be purchased in the form of apps. Apps are small software solutions. They have pre-defined functions for a limited remit and are comparable to the idea of services [10].

4.3. Technical solutions

In this section, several tangible solution for the supply chain are provided. Technologies, discussed in previous chapters, return in these solutions. These solution are smart objects or a system of multiple smart objects providing the fundamental physical requirements in combination with the desired data communication.

4.3.1. Intelligent conveyor belt systems

Even a relatively simple machine, like the conveyor belt shown in figure 4.3, can increase its value significantly if equipped with a proper embedded control and information processing the device. The main function of the conveyor belt system is to transfer material from one place to another. The embedded device can simultaneously host and implement a number of functions, as shown in figure 4.3. The intelligence on the device level extends its functionality, increasing its performance, reliability, and ability to integrate into more complex production systems [77].

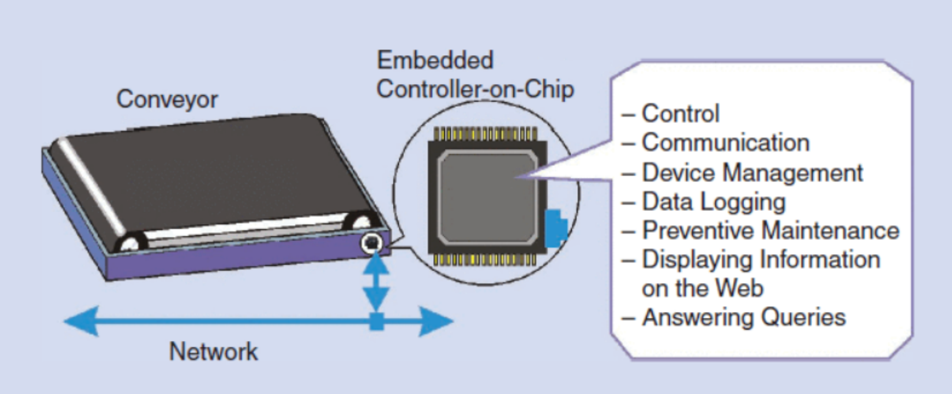


Figure 4.3: Simple conveyor belt system [77]

For example, connectivity function (the ability to communicate via networks is a very basic function of an intelligent machine) enables such a machine to communicate with other intelligent machines within a manufacturing cell, as well as with enterprise information systems and human operators [77].

The device can become an active communication partner capable of describing its functionality to other devices to dynamically form the communities aimed at the implementation of new production goals. This communication is likely to be based on RFID tags and readers, providing the controlling system to integrate the conveyor belt into the cyber system and making it possible to initiate commands which are summoned through IoT and IoT. The RFID in combination with other sensors (visual scanners, x-rays, weight scanners, et cetera) can constantly provide an overall identification of the conveyor belt resulting in a CPS which can make centralized decisions over the whole system, shown in figure 4.4 [77].

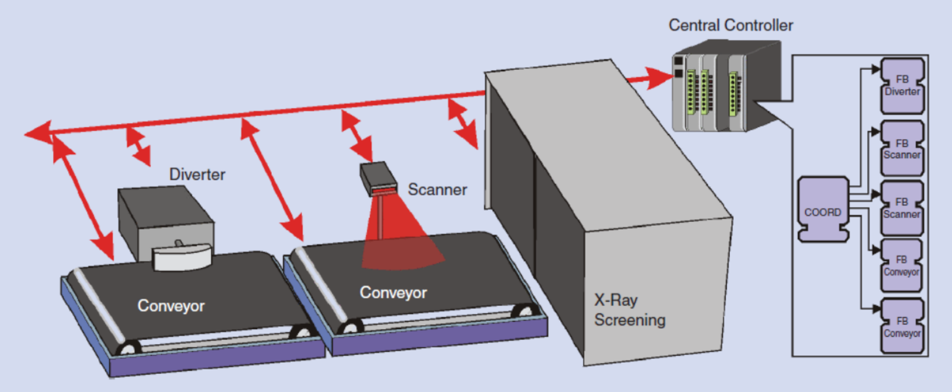


Figure 4.4: Intelligent conveyor belt system [77]

The monitoring of belt conveyors is analyzed by Pang and summarized in the following paragraphs [57]. Today, most critical components of belt conveyor systems are monitored in real time. Conveyor belt monitoring (CBM) has become an established tool for maintenance programming and the determination of control strategies of belt conveyor systems. In the future, belt conveyor systems will have intelligent monitoring and control systems that keep track of the situation on the belt and the operational status of the system. However, traditional technologies are currently not integrated into modern intelligent CBM systems for gathering efficient information, building decision support system and data mining. The main reason is that the information collected by traditional CBM technologies is hard to be represented and interpreted by computer systems. In addition, the combination of different technologies to monitor most of the conveyor belt parameters simultaneously causes system complexity.

A solution is the Embedded Conductive Detection (ECD) for CBM, a novel Nondestructive Test (NDT) technology. Primarily the ECD system is composed of outside sensors and a magnet matrix that is embedded in the carcass of the conveyor belt. The ECD system is designed to monitor the conveyor belt's situation and to measure most of the conveyor belt parameters simultaneously for a future intelligent CBM and control system. This system adopts magnetic conductive theory to overcome limitations of traditional CBM technologies and to gain most advantages of a modern CBM and the characteristics of absolutely maintenance free, long lifetime, non-contact monitoring, NDT, passive measurement, and so on. The ECD system provides a simple data acquisition approach where the collected information is directly comprehensible to an intelligent system.

Condition monitoring of belt conveyors is an established part of maintenance programs for many material handling operations. Typical methods are x-ray, ultrasound, eddy current, inductance and electromagnetic. Of these these methods, electromagnetic has been used most widely. Current technology employs a combination of techniques. The fundamental concept is to create a magnetic or electrical path. Any changes in the belt characteristics from damage or motion will alter the path and generate an output signal.

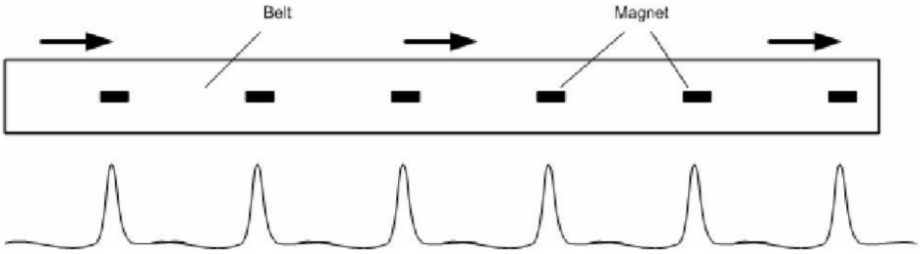


Figure 4.5: Primary principle of the ECD system [57]

The ECD system detects and measures most of the relative parameters of belt conveyor situations. The primary principle is to use a magnet matrix embedded in the carcass of the conveyor belt to collect a relative magnetic signal that exposes belt conveyor situations when magnets pass through outside sensors, as can be seen in figure 4.5. Each magnet produces a signal while passing magnetic field sensors. The magnetic field sensors measure magnetic fields and/or magnetic flux by evaluating a potential, current, or resistance change because of changes of field strength and direction. The outputs of magnetic field sensors can be an analog current, voltage or frequency, or a digital, parallel or serial computer signal, which match the requirements of industrial measurement standards and data communication realization.

The ECD system mainly detects and measures belt parameters of identities, positions, vibration, speed, wear, tensions, and so on. The objectives of monitoring and measurement principles can be extended to by composing the conveyor belt with a magnetic matrix with the use of several magnetic lines. This provides the systems with more information regarding the materials on the conveyor belt which offer more possibilities to the system. This is the first step to Intelligent Belt Conveyor Monitoring and Control (IBCMC) system.

The following paragraphs of this section are a summary of IBCMC by Pang [56]. One feature of the IBCMC system is the ability of automated data analysis that indicates abnormalities during BCS operations and evaluates the overall BCS status. To do so, several artificial intelligence technologies were employed. Fuzzy logic was applied for evaluating the conditions of monitored parameters and BCS components. The algorithm of fuzzy knowledge representation enables the IBCMC system to represent collected data and information as knowledge that can be used by the intelligent system for diagnostic reasoning and decision-making. Bayesian inference method was employed to evaluate system uncertainties and predict system failures.

The decision-making was achieved by case-based reasoning based on the knowledge stored in the IBCMC system, which has been built as a knowledge-based expert system (KBES). Knowledge acquisition is always a bottleneck for developing knowledge-based expert systems. A simulation-based knowledge acquisition approach was developed and implemented for this research project. One unique aspect of this method is that the bottleneck problem can be solved by the use of software model in discovering operational solution and maintenance strategies in BCS performance. From experimental results it was found that that the knowledge required by the IBCMC system can be sufficiently derived from system modeling and simulation. The simulation-based approach was able to provide accurate enough outputs for system diagnosis and correct enough maintenance and operational control decisions. This method shortens and simplifies the knowledge acquisition process and shows its efficiency and accuracy of building up knowledge bases in IBCMC. The application of KBES in IBCMC provides a systematic procedure for accumulating domain knowledge for optimizing BCS performance and retrieving past experience quickly and precisely. The advantages of applying KBES include (1) well accessible and extensive knowledge from domain specialist and past experiences can be accumulated and reused continuously and consistently; (2) the deviations in expertise among different operators can be overcome; and (3) human effort can be reduced with the assistance of the intelligent system.

Agent-based technology, as another artificial intelligence technology, has been employed by the IBCMC system for system integration. In belt conveyor monitoring, the monitoring systems of most BCS components are already available but distributed in different fields of a BCS. The organization and integration of individual monitoring systems are based on monitored BCS components. The implementation of the IBCMC system has proven that the integration of the data and information from individual monitoring systems and monitored aspects is able to significantly reduce the complexity of the overall monitoring system and enhance the payoff of developing the monitoring system. Besides autonomy, an agent of one BCS component is able to communicate and cooperate with other agents via the agent of system coordination. An agent-based IBCMC system has been implemented and tested in laboratory environment. Results showed successful single agent functioning and multiple agents' cooperation. The application of agent technologies in IBCMC was approved feasible and capable.

The automation of the monitoring and operational control of belt conveyors is likely to become a widespread research topic and will benefit the future of the industry using belt conveyors. AI technologies are feasible and capable to realize the intelligent abilities and add enough significant worth to be introduced into the applications of intelligent monitoring for belt conveyors. Since the development of intelligent belt conveyor monitoring and control is still at early stage, developing such an intelligent system may enable belt conveyor industry to set an industrial standard

4.3.2. AGV

An AGV is a driver-less autonomous transport system, illustrated in figure 4.6 used for horizontal transport of materials. AGVs can be used in all types of environments with all types of materials. AGVs offer transport of materials between flexible pick-up and delivery points. A typical procedure starts at the pick-up point, the AGV arrives and receives materials from another piece of equipment, drives to the delivery points where the material is transferred to another piece of equipment. Preferable is to combine the pick-up and delivery point, for optimum occupancy of the AGV.

Figure 4.6: AGV system [52]

The routing is controlled by the system via a smart grid. The system communicates with the AGVs through the smart grid. The communication can be based on RFID. Both are integrated with multiple sensors to transfer information allowing the system to control the AGVs as efficient as possible. The system can optimize the path of multiple AGVs while maintaining the lowest waiting systems for the whole system.

AGVs come in all possible sizes making it possible to transfer all kind of materials. AGVs can be designed to transport high-weight materials, such as 40 ton-containers but also for smaller packages. The transfer between the AGVs and other pieces of equipment is dependent on the preferences. AGVs can be implemented with equipment but it can also be outsourced to the other pieces of equipment which place the material on the AGV.

According to Sinriech, it is desirable to have the smallest number of vehicles in the system but still be able to achieve the performance requirements [66]. In most studies the systems performance is measured in terms of throughput. As additional vehicles are added to the system the throughput performance increases due to additional material flow capacity. However, the addition of more vehicles can result in increased congestion. Using too many vehicles in the system can cause the throughput to go down due to heavy traffic and blocking of the vehicles, causing delays in completing their tasks. This is both an economical and operational waste. This leads to the assumption that the systems performance can be described as a concave function which reaches its maximum subject to both trends, the additional flow capacity and the reduction in flow due to congestion. Deterministic based methods have limited capabilities due to their static nature and their simplifying initial assumptions. These assumptions are often made because of the complexity of the problem, the number of parameters that affect the solution, and the interaction between them. For example, the availability of vehicles is affected not just by their number but also by their mutual interference and blocking which is again influenced by the number of vehicles in the system. Also, the management of idle vehicles and empty vehicles dispatching is a function of the operational policies used. These methods can only be used as a starting point but have to be verified by means of simulation.

The model developed by Sinreich combines the system performance and the costs related to that performance in one optimization model and determines the number of vehicles needed in the system based on a combined measure. System performance will be measured by the utilization, which is defined as the ratio of completed parts to the total number of parts that have arrived. These parameters have been set into an decision table where the utilization is plotted versus the amount of AGV's. Decision tables have to be created as a part of the design stage of a new system. In most cases the cost information and simulation results already exist. All that is left is to implement the suggested model and check several operation policies. By creating these tables, the designer enables management to consider several operation options and making more efficient decisions.

However, there is another proposition to improve performance according to Nayvar [53]. An alternative to increasing the AGV fleet size in order to improve the availability of vehicles is to introduce vehicles with multiple load carrying capacity. This paper attempts to study the effect of different dispatching rules in the case of multi-load vehicles, on the overall performance of an AGVS. A comparison between the performance of a fleet comprising unit load vehicles is also made with that of multi-load vehicles. This resulted into the following conclusion: For the same fleet size, multi-load vehicles outperform unit load vehicles in terms of production rate and flow-time at high levels of shop loading, an increase of 12% in production rate and a decrease of 13% in flow-time. At low shop loading level, the performance of multi-load vehicles was better when the system was constrained due to limited number of vehicles. However, with larger number of vehicles the performance of multi-load vehicles was lower than that with unit load vehicles as low levels of shop loading. This is because the loaded travel time in case of unit load vehicles is higher. At high shop loading, less number of vehicles can do the job in comparison with unit load vehicles. For the system under study, the reduction was to the tune of one vehicle. Assumptions made during the various steps of problem formulation and simulation analysis limited the scope of this research. Conclusions drawn from the statistical tests conducted are valid for this system only. But it shows potential for further research.

The control of AGV systems is clarified by Mantel and summarized here [47]. One of the three main issues of an AGV system is the operational control. Mantel states that operational transportation control consists of two hierarchical levels: job control and traffic control. The first mentioned, upper, level routes and schedules the AGVs, given the transportation tasks to be performed. The second, lower, level consists of simple traffic rules (e.g. an AGV that comes from the right goes first).

First, it is important to decide upon the interaction between the operational control of the transportation system and the operational control of the production system. The structure of the production system determines to a great extent the selection of the production and transportation control strategy. One should distinguish two main structures: the flow-shop and the job-shop configuration. It may be decided to control production and transportation separately (e.g. schedule production tasks first and, taking the resulting time scheme as a starting point, subsequently schedule the transportation tasks required) or to integrate both control activities. The interaction between production and transportation control seems to attract little attention in the literature. Mostly they are separated; in fact most authors assume a certain arrival pattern for transportation tasks and restrict themselves to the control of the transportation system.

The transportation control is either centralized or decentralized. A centralized control implies that all transportation tasks are concurrently considered when the vehicles to perform them are routed and scheduled. In contrast, the First Encountered First Served rule (i.e. a vehicle makes a tour and performs the first transportation task it encounters, in other words an AGV looks for work) is a decentralized way of control, that is typically suited for a single-loop and a tandem configuration. In the remainder of this section we will restrict ourselves to centralized control policies. Another classification of transportation control is to distinguish think-ahead and no think-ahead policies. Think-ahead implies that known tasks are combined to routes such that empty travel time is minimized. These classifications can be combined for different ways of control.

The operational AGV control policies are discussed, which constitute the upper hierarchical level of operational control. As stated before, this level controls the assignment of transportation tasks to vehicles. Knowing that assignment, it is possible to deduce the routing and time schedule for each AGV. Then, given the track layout, one may predict where the AGVs interfere with each other, which results in congestion. The lower level of control, the traffic control, effects the amount of congestion. If this is too high, it may be tried to find blocking-free routes by rerouting the AGVs. Generally, this will lead to a revised task assignment. One of the advantages of creating blocking-free routes is that the travel time variances are reduced, so that the routing optimization problem gets a more deterministic character.

4.3.3. AutoStore system

AutoStore, illustrated in 4.7 is an automatic storage system operated by robots which main purpose is to improve the quality of the internal logistics. The product is based on bins, stacked on top of each other inside an aluminum grid. Then, robots pick, organize and store the bins in a logical system. With advanced algorithms the robots communicate via RFID for smooth operations. One of the key factors to reduce the picking-time per unit for this system is that the robots always make sure that high-runners (often used bins) are placed at the top levels of the grid, whereas low-runners (less used bins) are placed at the lower levels of the grid.

Figure 4.7: Autostore system [61]

The robot has two sets of wheels that enable it to move along two axes. This makes it possible for all robots to reach any position on the grid. The robot is equipped with a lift for picking up, carrying, and placing bins that are stored in the grid. The robot communicates with the control system via RFID and is automatically recharged when needed (charging is normally done at night).

The grid is an aluminum structure organized in rectangular cells. Each cell has room for several bins that are stored on top of each other. Different configurations of height and shape are possible, making the AutoStore grid able to surround pillars and other obstacles. There are tracks for the robots on top of the grid.

There are some concrete aspects of this product that gives it its competitive advantage. Placing all products in the grids, while leaving no space unused between the grids, contributes to optimization of the use of storage-space (up to 60%). Furthermore with this new way of thinking, robots are collecting all the goods at a high rate, leaving fewer burdens on the employees per day. The robots are battery driven, and they will at all possible opportunity return to a docking station for charging, making sure that they can be operative at all times. Given that this is a green line product, this can also be a strong advantage [61].

4.4. Conclusion

The technologies CPS, IoT and IoS are currently theoretical technology concepts, which therefore, are intangible and hard to work with for a technology supplier and, especially, technology user. Hence, a practical reflection of these concepts is attributed to smart objects. The collaboration of multiple smart objects can result in a smart factory for Industry 4.0 or an ILS for Logistics 4.0. Smart objects consist of several hardware-based and software-based technological configurations.

The hardware-based technologies enable functions as automatic identification and localization (by e.g. RFID tags and readers), M2M communication (by e.g. wireless networks), energy supply (by e.g. thermogenerator modules), sensing and actuating (by e.g. MEMS), data and information processing (by e.g. microcontrollers) and Human-machine interaction (by e.g. voice control). These functions are proven to be important to the essence of Logistics 4.0. The software-based technologies enable slightly different functions for smart objects, namely AI, autonomy of action, advanced data analytics and digital integration platforms. The software-based technologies predominantly are used to enhance the functionality of information-processing unit of smart objects.

A structured combination of the hardware-based and software-based technologies can provide solutions for the logistics system. The combinations translates the interconnection of these technology disciplines and makes them implementable. The decision of which identified technologies are used to form an smart object is strongly dependent on its usage and its application. For logistics systems, the solutions can be translated into an highly-effective transport system capable of communicating with the controlling entity and implementable in an ILS. .

5

Implementation

This chapter discusses the implementation of Logistics 4.0 into the supply chain. After a short introduction, the architecture of CPS is elaborated. Followed by more specific structures for implementation, namely the hierarchical structure of ILS and the hierarchical structure of smart objects. Subsequently, a scale of implementation is elaborated which provide a measurement tool for implementation. Finally, the findings are summarized in the conclusion.

As stated before, the main challenges within the theory of Industry 4.0 and Logistics 4.0 is the high investment costs and sufficient IT knowledge. The journey towards implementing the Industry 4.0 vision will involve an evolutionary process that will progress at different rates in individual companies and sectors. Hereby, it is essential to have a well-structured organization. In this chapter several structures are provided that will provide each company with a solid foundation for implementing Logistics 4.0.

In the ILS, products find their way independently through production processes and are easily identifiable and locatable at any time, pursuing the idea of a cost-efficient, yet highly flexible and individualized mass production. Based on these key elements, a scale of implementation is provided which shows the level of implementation of a company.

5.1. Architecture of CPS

CPS is the main component of Logistics 4.0 which involves all other components. Since CPS is in the initial stage of development, it is essential to clearly define the structure and methodology of CPS as guidelines for its implementation in industry. To meet such a demand, a unified system framework has been designed for general applications.

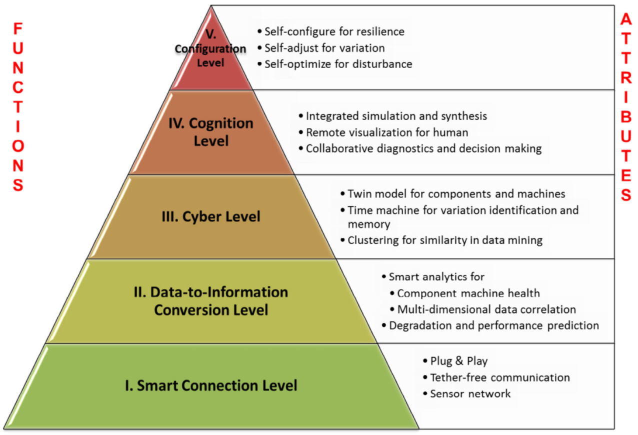


Figure 5.1: 5C architecture for implementation [41]

The proposed 5-level CPS structure, namely the 5C architecture, provides a step-by-step guideline for developing and deploying a CPS for manufacturing application and is summarized by Lee [41]. In general, a CPS consists of two main functional components: (1) the advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space; and (2) intelligent data management, analytics and computational capability that constructs the cyber space. However, such requirement is very abstract and not specific enough for implementation purpose in general. In contrast, the 5C architecture presented here clearly defines, through a sequential work flow manner, how to construct a CPS from the initial data acquisition, to analytics, to the final value creation. As illustrated in figure 5.1, the detailed 5C architecture is outlined as follows:

- **Smart connection**: Acquiring accurate and reliable data from machines and their components is the first step in developing a CPS application. The data might be directly measured by sensors or obtained from controller or enterprise manufacturing systems. Two important factors at this level have to be considered. First, considering various types of data, a seamless and tether-free method to manage data acquisition procedure and transferring data to the central server is required where specific protocols are effectively useful. On the other hand, selecting proper sensors (type and specification) is the second important consideration for the first level.

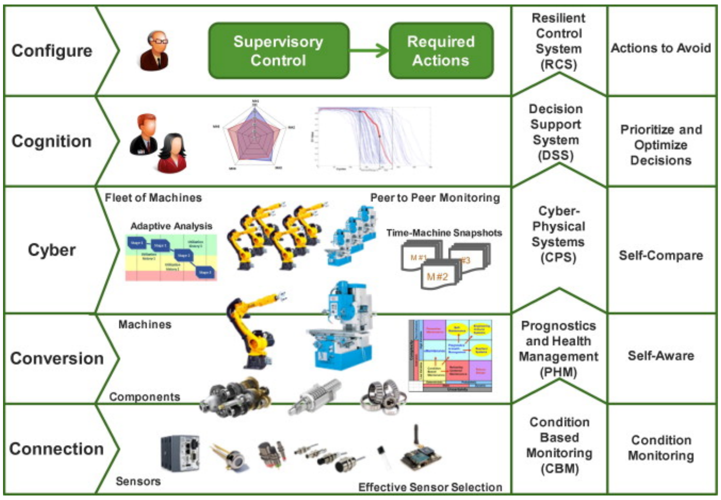


Figure 5.2: Applications and techniques associated with each level of the 5C architecture [41]

- **Data-to-information conversion**: Meaningful information has to be inferred from the data. Currently, there are several tools and methodologies available for the data to information conversion level. In recent years, extensive focus has been applied to develop these algorithms specifically for prognostics and health management applications. By calculating health value, estimated remaining useful life and etc., the second level of CPS architecture brings self-awareness to machines which are specified per level in figure 5.2.

- **Cyber**: The cyber level acts as central information hub in this architecture. Information is being pushed to it from every connected machine to form the machines network. Having massive information gathered, specific analytics have to be used to extract additional information that provide better insight over the status of individual machines among the fleet. These analytics provide machines with self-comparison ability, where the performance of a single machine can be compared with and rated among the fleet. On the other hand, similarities between machine performance and previous assets (historical information) can be measured to predict the future behavior of the machinery.

- **Cognition**: Implementing CPS upon this level generates a thorough knowledge of the monitored system. Proper presentation of the acquired knowledge to expert users supports the correct decision to be taken. Since comparative information as well as individual machine status is available, decision on priority of tasks to optimize the maintaining process can be made. For this level, proper info-graphics are necessary to completely transfer acquired knowledge to the users.

- **Configuration**: The configuration level is the feedback from cyber space to physical space and acts as supervisory control to make machines self-configure and self-adaptive. This stage acts as resilience control system apply the corrective and preventive decisions, which has been made in cognition level, to the monitored system.

5.2. Hierarchical structure of ILS

ILS is a more integrated form of CPS which is specific for the logistics system. Just like the architecture of CPS, an ILS must have a structure which supports the strategy of Logistics 4.0. The hierarchical structure of the ILS has multiple functional components which are presented in figure 5.4. This figure shows the five layers ILS system covering management and coordination, adaption, scheduling, supervision and control which in natural way integrate and vertically orders (in time, frequencies of interventions, aggregation levels) wide spectrum of decision making and optimal control functions, that additionally are supported by integrated data, knowledge and tools basis equipped with dedicated professional decision support systems. The kind of hierarchical logistics systems is provided by Adamski as an hierarchical integrated intelligent logistics system [5].

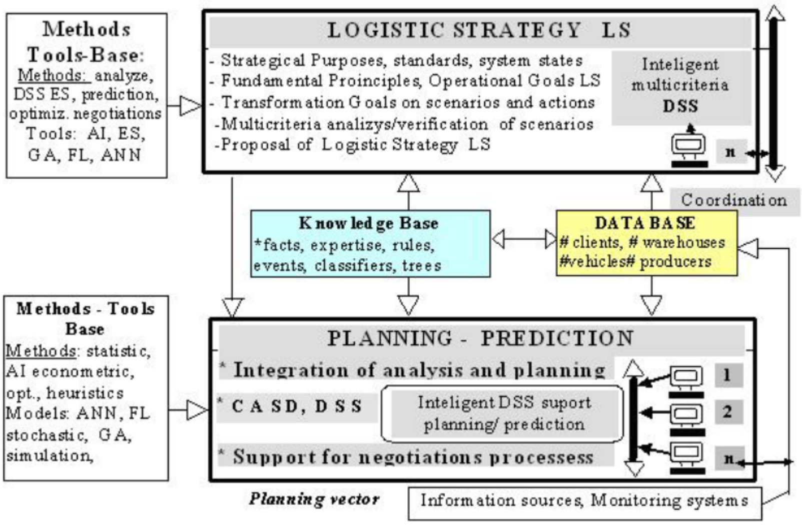


Figure 5.3: Upper Layer of the Logistic Hierarchical ILS system [2]

At the upper layer ILS system where the system-wide logistic strategy is created, , illustrated in figure 5.3, the multi-criteria is implemented which adequately integrating different hierarchical system premises, tasks assignment preferences for layers and different subsystems, by proper multi-time horizons representations of compromises between conflicting criteria and requirements of different subsystems.

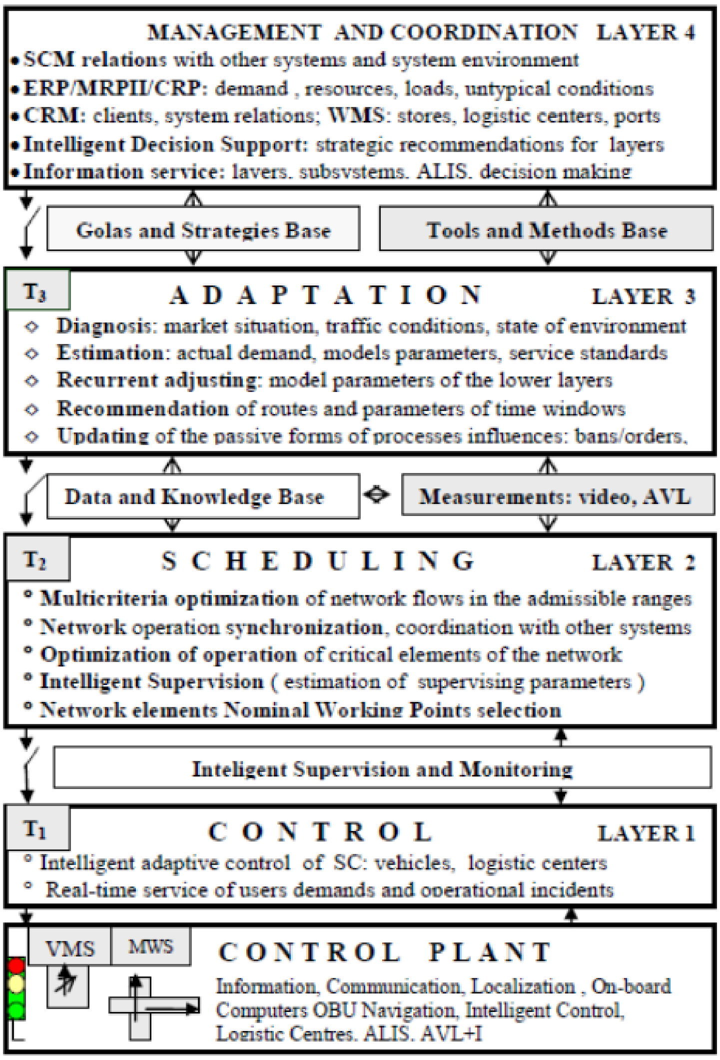


Figure 5.4: Hierarchical Management, Surveillance and Control ILS System [2]

- **Management and Coordination Layer**: In this layer the management actions concerning the flows of materials, means, information in the areas of supply, production, distribution from the point of view of clients are realized. The integrated production management consists of several stages: activity targets establishing, demand prognosis, organization of production means, decisions optimization and costs analysis. The management models include the dynamic of daily production (increasing sizes of production and revenue), different measures of operational efficiency (productivity and make use of system), material and financial resources consumption, social environment of production processes. The general problem to be solved in this layer concern minimization of the general logistic costs concurrently with maximization of the margin profits in production and sales.

- **Adaptation Layer**: to be of importance due to adaptation/ accommodation of using tools, procedures and principles, information systems to specific conditions of a given company as well as to dynamic system environment (clients, competition, market). In particular, this concerns the adequate reaction on new clients service standards, new forms and character of internal and external relations of the company. In consequence this layer introduces to the system integration, unusually important element of system functional flexibility and intelligence, minimizing the risk of lack of "openness" in introduced solutions. The proposed approach in fundamental way differs from presented in literature because in it information/informative systems create only some environment for execution of the intelligent integrated supervision, control and management functions on different levels of ILS system.

- **Scheduling Layer**: The forecasting sales plan and input data for various schedules are the main inputs to this layer from the adaptive layer. The schedules determine the principles of production (technologies, specifications e.g. networks of activities, times of technological stages). As a result of operation of this layer the following schedules arise: production schedule (production tasks accommodated to production capacity and optimized in the context of general costs and capacity compatibility); schedule of material consumption (accessibility store levels of materials, supplementary products and schedule of shopping's); schedule of distribution of final products to buyers. In this layer the markers for supervising layer are defined.

- **Supervision Layer**: In this layer the real-time monitoring of the logistic system environment is realized (e.g. market, backlog of orders) as well as the monitoring of parameters of the system (operational efficiency of the system resources, system reliability, shortages, costs, demands). The modern multi-media technologies are used for advanced logistic information services, visualization, warning and alarm generation purposes. In consequence wide spectrum of professional anticipation and preventive actions practically on all layers of the proposed system can be realized.

- **Control Layer**: Very important new functional element at the bottom direct control layer concerns the full integration of the tasks of intelligent supervision with the intelligent adaptive control actions, see figure 5.5, realized by the Poly-optimal Integrated Adaptive Control (PIACON) control method [2]. The practical proposals of PIACON traffic multi-criteria control capabilities realized in hierarchical multilayer adaptive, optimization and direct control structure were presented by Adamski in 1999 [4], 2003 [1] and 2006 [2].

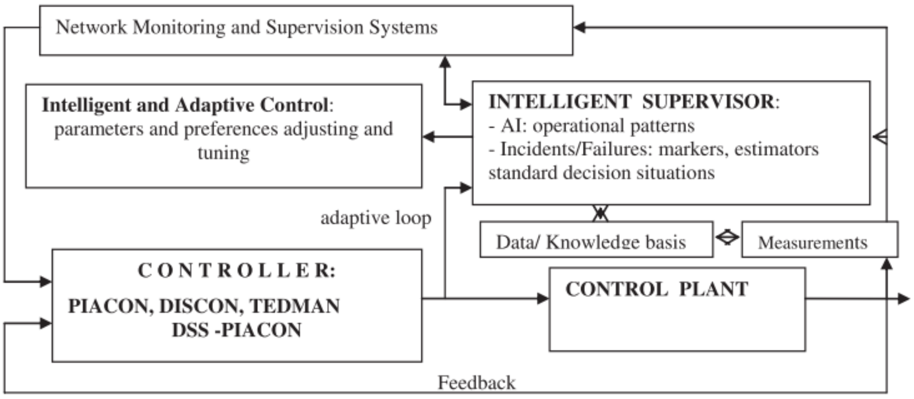


Figure 5.5: Intelligent Supervision and Control realized in bottom direct Control Layer [2]

5.3. Hierarchical structure of smart objects

The smart objects are the most physical components of the ILS. As the ILS must have a hierarchical structure, the smart objects must fit in this structure. Therefor, it is also necessary for the smart objects to have an hierarchical structure. The hierarchical structure of the smart objects is essential during the design stage, the so-called end-to-end engineering strategy must ensure a structure which transfers a signal in a logical manner through the product - a structured transfer of a cyber signal to the physical action. Hereby, the different layers are, in hierarchical order, physical layer, smart layer and communication layer and can be seen in figure 5.6 [25].

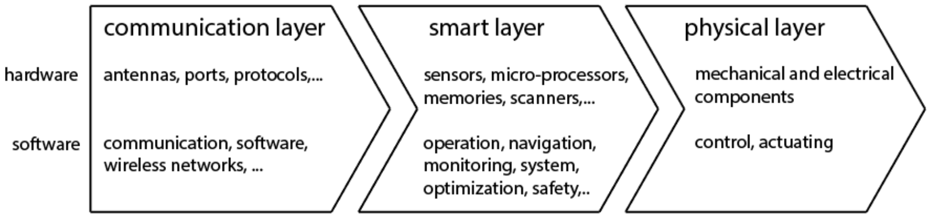


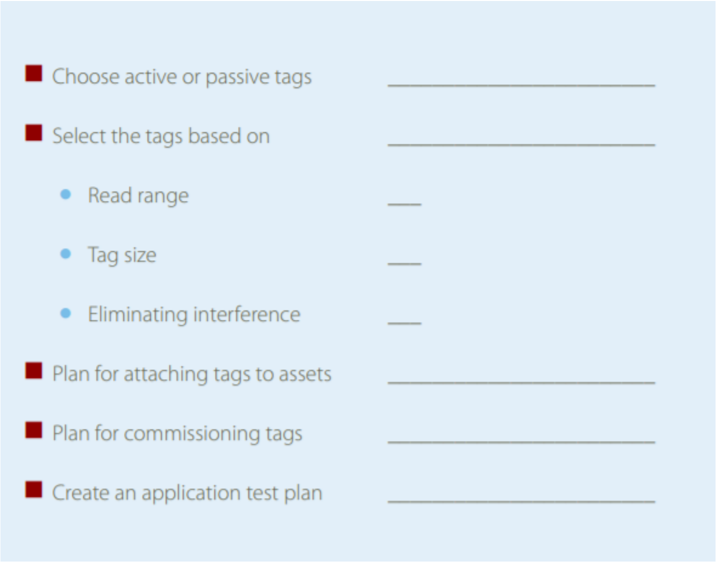
Figure 5.6: Hierarchical structure within the smart products of Logistics 4.0 [25]

- **Communication layer**; the communication layer describes the communication between the smart products and ensures that the set of smart products is optimized in their task. This means that the AGVs drive the most efficient route and have minimal waiting times.
- **Smart layer**; the smart layer ensures the capability of operating, navigating, monitoring and optimization with the use of sensors, processors and memories. This means that an AGV drives to the right place without bumping into anything.
- **Physical layer**; The physical layer describes the mechanical and electrical elements of the smart products which ensures that the products are capable of their main function. This means for AGVs driving and steering.

This structure will secure that smart products are capable of interacting within the hierarchical structure of ILS. The hierarchical structure of ILS is maintained in the structure of the smart products.

5.4. Implementation of RFID

This section describes the manner of implementation for RFID tags and readers, created by Omni-ID [55]. As the above sections are focused on the structure of the whole implementation, it is also important to provide guidance for certain technologies. Therefor, the implementation of RFID can be seen as an checklist, illustrated in figure 5.7, which covers the essential choices of the implementation.



- Choose active or passive tags
- Select the tags based on
  - Read range
  - Tag size
  - Eliminating interference
- Plan for attaching tags to assets
- Plan for commissioning tags
- Create an application test plan

Figure 5.7: RFID deployment checklist [55]

One of the first decisions to be made in designing an RFID system is whether to use active or passive RFID tags. Both active and passive tags have developed significantly over the past several years. Because active tags have a battery in them, they have certain advantages over passive tags. Their signal is stronger, and they emit a signal without activation by an RFID reader, so they can constantly emit their identity. There are also features of passive tags that are superior to active tags. The most significant is cost; the initial per-tag cost is much lower for passive tags. Passive tags also have a much longer lifespan, lasting indefinitely, while active tag batteries typically must be replaced within two-to-three years, adding both infrastructure and labor costs. The most important (dis)advantages of both can be seen in figure 5.8.

	Active	Passive
Signal strength	Stronger	Weaker
Signal availability	Always on	Responds when read
Size	Larger	Smaller
Initial cost	Higher	Lower
Maintenance	Replace every 2–3 years	Indefinite lifetime
Environment	Available for all environments	Available for all environments

Figure 5.8: (Dis)advantages of active and passive RFID tags [55]

The next decision to be made is on what technology the tags are based on. This decision is made on the preferences on read range, tag size and eliminating interference. This decision chooses an antenna type. There are many antenna types, they can be grouped into two main categories, circular and linear, referring to the polarization of the signal emitted. A circular antenna reads from a much wider angle and a shorter distance than a linear antenna, and it can read tags in different orientations. A linear antenna can have better read performance and accuracy when the tag orientation is controllable.

Read range: The primary consideration when selecting RFID tags is finding the optimal balance between size and read range. The right read range is based on the physical distance between your assets and the RFID reader. For example, a trucking operation will need to easily identify individual trucks from a distance, necessitating RFID tags with a long read range. In a retail outlet, or any environment where many assets are close together, a long read range can cause signal interference, making it difficult to take inventory on just one aisle or section. When assets are in close proximity, a shorter read range works best.

Tag size: As a general rule of thumb, the larger the tag, the longer its read range. For many applications, tag size is not an issue, because there's plenty of room on the asset to locate a tag. However, on smaller high-value assets such as electronic equipment, size can be a critical factor. The face plate of many electronic devices is already competing for space between the various controls, and airflow ducts. Placing a tag over an airflow intake can cause the equipment to overheat and fail. Over the past several years, the RFID industry has developed new RFID tags with smaller footprints.

Interference:After read range and size, the most important consideration in planning your implementation is the electromagnetic environment in which you'll be installing your RFID system. All materials have dielectric properties, which always impacts the operating frequency. A standard dipole RFID tag takes on the dielectric properties of the material it's on, which is why those tags have historically not worked when used on materials like metal or liquid. Today, tags are available that are optimized to work either on- or off- or near-metal. In planning your implementation, it's important to choose a tag type that will work effectively on all of your assets.

Other decisions may be less obvious but are equally important to a successful implementation, such as how and where to attach the RFID tag to an asset. A secure attachment is required to accurately track and identify assets. As the tagged products are always different, just like the procedure, there is no exact way to perform the attachment. This has to be designed per situation. However, a tether was created to add on the tags and additional testing proved that the tag could be read successfully from multiple directions, so hanging the tag backwards or sideways would not cause a problem. The new tether allowed the team to tag this asset as part of their RFID inventory tracking and management system, despite its size limitations. The most important rule is that the attachment requires a clear but simple procedure for employers, showing the correct tag location for each class of asset, and required each tag to be placed on a clean, flat surface, applying pressure for five seconds when placing each tag.

As with tag attachment, it is important to think through how to commission RFID tags – the process of programming each tag with a unique identification number. Commissioning tags after they are applied to the asset and stored in the inventory location is not recommended – it is too easy to mistakenly commission more than one asset when working in a crowded inventory environment. Tag commissioning should be done away from the final inventory location, either by the tag vendor or in-house.

When programming sequential numbers into RFID tags, consider having the RFID tag vendor ship the tags pre-programmed with the identification numbers. The ease of receiving tags already commissioned with the numbers you provided makes your deployment faster and eliminates the need for you to set up an in-house commissioning line. This method works well if you are tagging a row of inventory locations or giving assets numbers for the first time, because you will be following a sequential block of numbers.

If, on the other hand, you have an asset base that already has identification numbers, and they are out of sequence, it may be easier to set up an in-house commissioning line. For example, a row of assets in a data center contains many items that have been bar-coded and subsequently moved around, resulting in a non-sequential group of identification numbers on any aisle. The easiest way to commission tags for these assets is to collect the data for the whole aisle and then program tags for that aisle in a separate commissioning area. A commissioning line can be set up with either an RFID reader, or with an RFID printer. Standard dipole tags can be commissioned through an RFID printer, but until recently, tags that worked on metal could not be commissioned that way because they are attached to a thick substrate. New solution now can commission tags by printing on the chip element with an RFID printer, and then attach the chip to the substrate like a label. As with many other recent technological advances, this new offering makes it possible to implement RFID as easily in mixed-material environments as it has been previously in non-metal environments.

Once the RFID system is designed, ensure success by testing the system in the actual environment where it will be deployed. Because of the many sources of dielectric interference in the real world, the performance of an RFID system after implementation can vary significantly from lab test results. Many companies do initial testing in an an-echoic chamber, which cancels out dielectric signals from other sources. Similarly, product specifications are typically listed at the most optimal performance levels, without interference. Testing how your system elements work together, within your work environment, can uncover potential issues that can be solved before full deployment.

5.5. Scale of implementation

The implementation of ILS can be measured in five different categories. These categories contain the most important factors of Logistics 4.0. Within these categories, certain levels are described in which the different level of implementation is shown. Hereby, the preferred level indicates a completely integrated logistics 4.0 system - an ILS. The scale is constructed in four different levels where level 1 is the preferred level and the following levels indicate less integration of Logistics 4.0.

1. **Automation of transport**; the level of autonomous transport within the system. In an ILS, it is preferred to have autonomous transport from beginning to end. This can be simply checked by the level of human interference. Hereby, there are some critical points during the transport, namely the transfer from one transport equipment to another and at the beginning and end of the system.

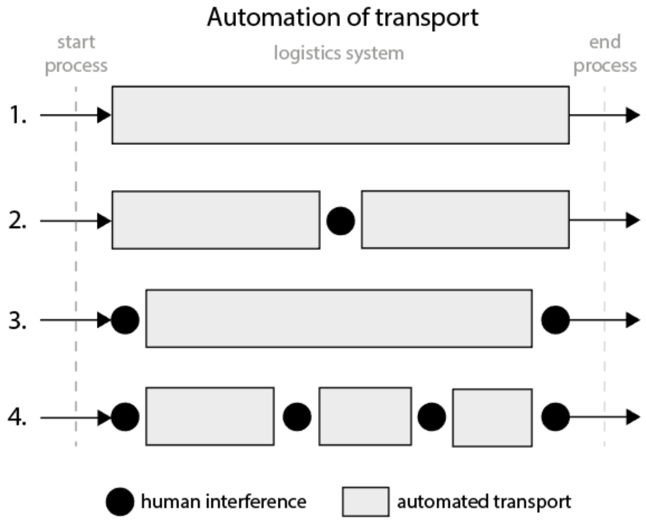


Figure 5.9: Different levels of automated transport

The different levels of automation of transport, illustrated in figure 5.9, are (1) A complete automation of transport during the whole process, (2) an automated transport process with a single human interference at transfer of transport equipment, (3) an automated transport process with multiple human interference at transfers of transport equipment and (4) an automated transport with human interference at all transfers.

2. **Identification**; the level of identification of the product during the process. The identification is dependent on the sector but in any case will contain knowledge about the product information, location, origin and purpose. Other elements of identification, which are dependent on the sector, can be weight, speed, temperature, etc.. The level of identification can be measured based on the preferred identification. The most preferable case is constant identification of the product. This results in constant knowledge of every product in the system - meaning constant knowledge of location, product information, purpose, et cetera. Hereby, there can be differentiated in multiple levels of identification regarding the constant identification. A system decreases a level when there is a black box during the process. A black box indicates that the product is in this part of the process but unknown whether the state of the product.

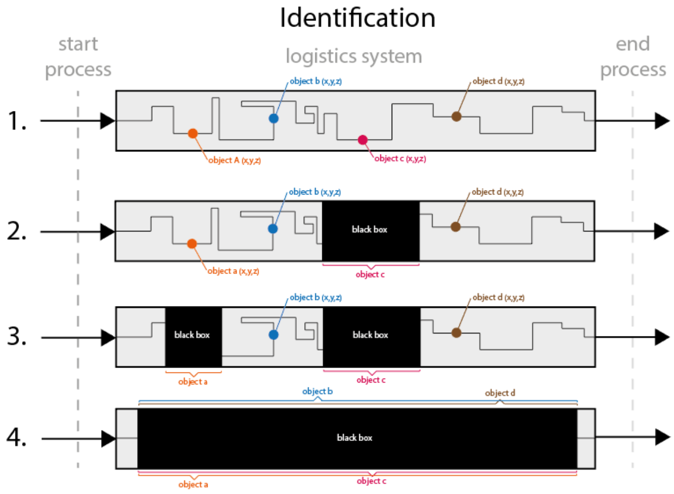


Figure 5.10: Different levels of identification

Figure 5.10 is an illustration of the different levels of identification, being (1) constant identification during the process, (2) constant identification during the process with one black box, (3) Identification in the process with multiple black boxes and (4) no identification during the process - one big black box. In the black box, there is no identification. However, with statistics an estimation of the identification can be made; meaning that it is possible to estimate the identification of a product with a known uncertainty.

3. **Interconnectivity**: the level of interconnectivity between the components in the logistics system. This can be measured by the amount of connected components in the systems relative to the total amount of components. As illustrated in figure 5.11, the desired level of interconnectivity (1) is interconnectivity of all components in the system, followed by (2) the interconnectivity is only missing one component, (3) the interconnectivity is missing multiple components and (4) there is no interconnectivity within the system.

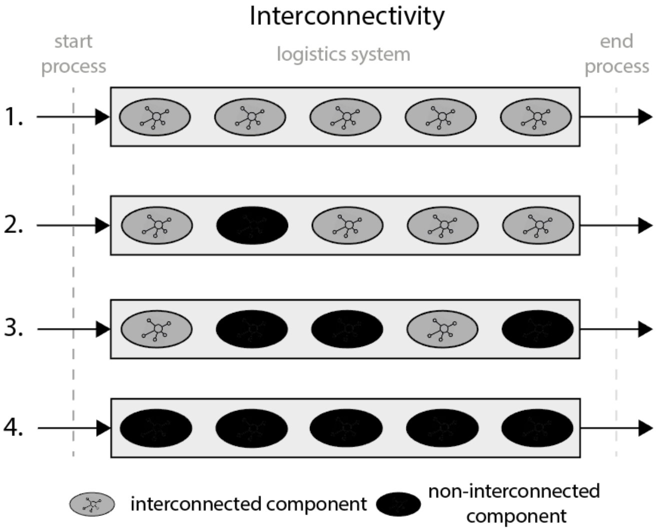


Figure 5.11: Different levels of interconnectivity

4. **Autonomous decision-making**; Autonomous decision-making by the controlling system is essential in logistics 4.0. Hereby, the level of autonomous decision-making is significant for the level of implementation. A completely integrated ILS can make decision over all components of the system. Hereby, the components must be integrated within the interconnectivity of the system. Keep in mind that these decision are preferred to be made by the controlling entity. The ILS is designed in making decision in the preferred cases and acting upon it and in unknown cases reporting to the human controllers when preferred not to.

   There is a correlation between autonomous decision-making and interconnectivity. Therefor, the different levels of autonomous decision-making is also illustrated by figure 5.11. The capability of autonomous decision-making requires at least interconnectivity, so in this figure the interconnectivity of the components is set equal to the possibility of decision-making. The preferred level of autonomous decision making is (1) when the controlling entity can make decisions over all components. Followed by (2) the controlling entity can make decision over all component except for one, (3) the controlling entity cannot make decision over multiple components and (4) there cannot be made autonomous decisions in the whole system.

5. **Flexibility and adaptability**; The vision of Logistics 4.0 states that it is preferable for a logistics system to directly adapts to possible changes being made by the controlling system. For example, the necessity when a certain part of the system is broken that other parts provide flexibility and adapt to the new best operational plan commanded by the controlling entity. Preferable is that every component can provide a certain level of flexibility and adaptability. However, this level of implementation is hard to measure due to the dependency of the applied sector, machines and procedures. Therefor, the desired level of

flexibility and adaptability must be defined by the business itself. This results in the preferred level of flexibility and adaptability: (1) every component in the logistics system has the desired level of flexibility and adaptability. Followed by (2) every component except one has the desired level of flexibility and adaptability, (3) multiple components do not have the desired level of flexibility and adaptability and (4) no components have the desired level of flexibility and adaptability.

5.6. Conclusion

The implementation of Logistics 4.0 requires a lot of structure. In order to make an autonomous logistics system, there is necessity of an hierarchical structure in all components of the system. An hierarchical structure provides a logical order of elements in which higher placed elements have more authority. Such structures are commonly described in literature and provide a guidance with the implementation of Logistics 4.0.

The structure of CPS is provided with a 5C architecture. The 5C architecture provides a step-by-step guideline for developing and deploying a CPS with different levels. At the lowest level, the acquirement of accurate and reliable data from the machines differentiates in considering the types of data and selecting types of sensors. The second level specifies the data-to-information conversion. This is analyzed at the cyber level which transfers all the information into better insights. These insights are generated into a proper presentation to the users in the cognition level. The highest level, configuration level, act as the supervisory control to make machines self-configure and self-adaptive.

The hierarchical structure of ILS has multiple functional components divided over five layers. This hierarchical structure has resemblance with the 5C architecture but has a slightly different, more business orientated, approach. The first layer is the management and coordination layer which general goal is to minimize the logistics costs while maximizing the margin profits in production sales. The followed adaptation layer introduces the integration of introduced solutions which are unusually important element of system functional flexibility and intelligence while minimizing the risk. The scheduling layers provides schedules of production, material consumption and distribution of the final products including for the introduced solution from the adaptation layer. The supervision layer is the real-time monitoring of the logistics system which all is controlled in the control layer different control methods, such as PIACON.

The hierarchical structure of smart objects is essential for smart object to fit in an integrated Logistics 4.0 system. Hereby, three different layers are described to make the objects capable of transferring data to the controlling entity and acting autonomous to received commands. The physical layer describes the mechanical and electrical components for control and actuation of the smart object, followed by the smart layer which ensures the capability of operating, navigating, monitoring and optimization with the use of sensors, processors and memories. The communication layer describes the communication between the smart products and ensures that the set of smart products is optimized in their task. This structure is an extension of the hierarchical structure of ILS resulting in optimal integration.

For the measurement of the implementation of Logistics 4.0 of a business, a scale of implementation is provided. The scale provides the possibility to measure the core values of Logistics 4.0 in a business. Based on this scale, a business can reflect on each core value and can obtain knowledge to reach an higher level of implementation. The scale provides measurement tools for the automation of transport, identification, interconnectivity, autonomous decision-making and flexibility and adaptability. An important side-note is that the efficiency of the scale is not yet proven.

The next chapter, *Current state*, provides the current state of logistics system. Hereby, the level of implementation of Logistics 4.0 is measured according a large scale survey of companies in every sector.

6

Current state

This chapter elaborates the current state of logistics systems. After a short introduction, the current state of the main strategy is elaborated regarding the main components of the strategy. Subsequently, the investment of the companies are discussed as this is found to be one of the main challenges. Followed by the expectations and the conclusion.

This chapter is written based on a study of a survey conducted with 235 German industrial companies. The surveyed companies belong to the manufacturing and engineering, automotive and process industries, as well as the electronics and electrical systems and information and communications industries. The key findings affect all components of Industry 4.0 but in this chapter only the logistic 4.0 relevant findings are elaborated. The study reflects on each company with the key components of Industry 4.0. The key findings affect all components of Industry 4.0 but in this chapter only the logistic 4.0 relevant findings are elaborated.

All the information in this chapter is extracted from this study by PwC and Strategy& [39]

6.1. Current state of the main strategy

The main strategy of Logistics 4.0 is horizontal integration through value network, vertical integration and networking manufacturing systems and end-to-end engineering across the entire value chain. The first significant drives is to integrate and better management of horizontal and vertical value chains. However, today only one fifth of the industrial companies have digital management of their key processes along the value chains; in five years' time, 85% of companies will have implemented Logistics 4.0 solutions in all important business divisions. The digitization and interconnection of products and services (smart objects, CPS, ILS, IoT, IoS) is a second important driver. The digitization level of products will rise substantially in the coming years. By 2020, 80% of the companies surveyed will have achieved a high degree of digitization of their products and services. The proportion of companies with a highly digitized product portfolio will increase by more than five times, from currently 7% to 40%.

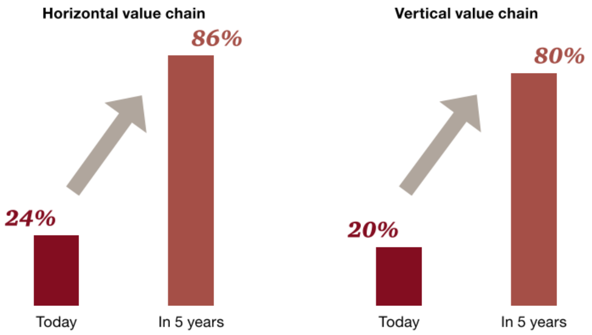


Figure 6.1: Degree of digitization of the value chain [39]

One quarter of the companies surveyed have already achieved a high degree of digitization. However, it is mostly only individual units and isolated applications that have been automated and digitized thus far. Two-thirds of the companies surveyed are already actively working on digitizing and further connecting their value chains. One fourth of the respondents already classifies the current degree of digitization of their value chain as high. In concrete terms, this means that most of the companies are already using or have implemented Industry 4.0 solutions in various divisions. The study shows that the level of digitization of the value chains will rise rapidly in the future. It is estimated that 86% of the horizontal and 80% of the vertical value chains will be highly digitized in five years. This kind of conscious investing in further digitization opportunities can be seen across all industry sectors.

About half of all companies surveyed are convinced that closer co-operation with value chain partners – combined with increased horizontal integration is already of very high importance today. This importance will increase considerably further given the growing level of digitization and connectivity. As far as the next five years are concerned, more than 80% of the companies surveyed expect that closer co-operation and increased horizontal integration will be of great importance. This likewise applies to all industry branches surveyed and both for users as well as providers of Industry 4.0 solutions.

The main driving force for closer co-operation and increased integration with other companies is the better satisfaction of customer needs in the context of new, digital business models. Shorter time to market and a higher innovation speed as well as an efficient division of labour, combined with more flexibility, are further reasons for the intensification of co-operation. According to the companies surveyed, the access to expert know-how and the minimization of risks play a less important role. Future horizontal co-operation is considered to be important by more than 96% of the companies in this sector.

6.2. Investment

Over the next five years, the industrial companies surveyed will invest, on average, 3.3% of their annual revenues in Industry 4.0 solutions. This is equivalent to nearly 50% of the planned new capital investments and an annual sum of more than €140 billion with regard to the European industrial landscape. As can be seen in figure 6.2, only a quarter of the companies have not yet considered it necessary to channel significant investments into Industry 4.0 applications. By contrast, one third of the respondents will take on opportunities to increase efficiency and ensure competitiveness as the most important investment challenge. These companies will invest on average 7% – a major part of the budget – in Industry 4.0 applications (this is equivalent to the average of the top three categories with investments over 4%).

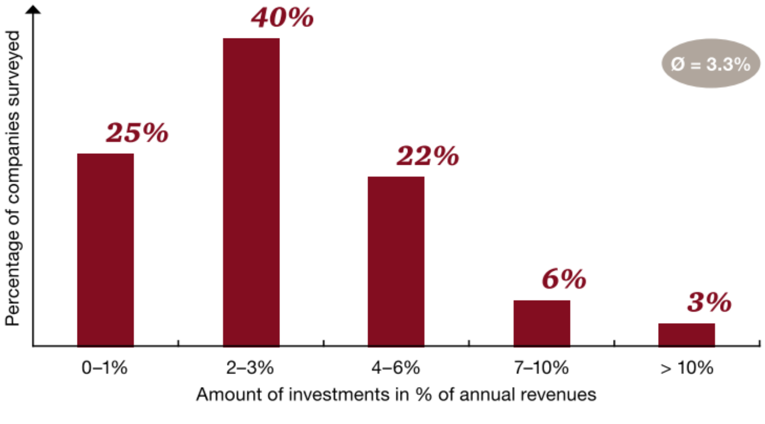


Figure 6.2: Average annual investments in Industry 4.0 applications [39]

Industry 4.0 solutions enable efficiency improvements and reduce costs along the entire value chain. The study's participants therefore place an equally high priority on investments in the entire supply chain, the digitization of product development and engineering, as well as in the automation of manufacturing. It is only investments in the digitization of sales that are rated slightly lower. Investments cover the entire range, from connections between operation materials, machines and logistics systems in the form of cyber-physical systems (CPS), through solutions of sensor technology to the exchange of data controlled in real time along the value chain. As can be seen in figure 6.3, the greatest concern of companies is to invest in the supply chain which shown to have high investment (average of 4,5%) by 57 % of the companies.

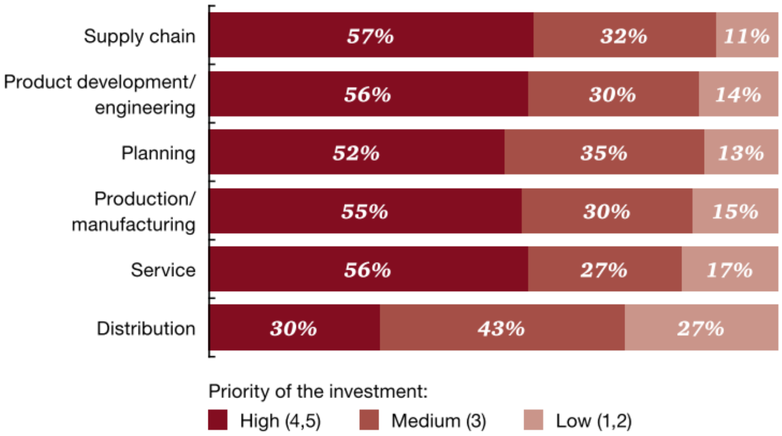


Figure 6.3: Industry 4.0 investments broken down by steps of the value chain [39]

6.3. Expectations

The fourth industrial revolution plays an important role in making long-term manufacturing efficiency possible. Over the next five years, the companies surveyed expect a noticeable quantitative benefit from the planned investment in Industrial Internet applications. They anticipate an average efficiency increase of 18% through digitized enterprises across all industry sectors. This is equivalent to an annual efficiency increase of 3.3%. In fact, more than one third of the companies actually see even greater potential.

The surveyed companies anticipate Industry 4.0 to yield additional annual savings in the amount of 2.6% on top of the usual cost savings. The expectations of the process industry for a cost reduction of 1.9% per year are considerably more conservative than those of the discrete manufacturing industries.

Regarding the qualitative benefits, the companies surveyed have very high expectations with regard to better planning and control in manufacturing or in logistics, higher customer satisfaction and greater flexibility in manufacturing. Better planning and control are closely connected with the integration of horizontal value chains across companies and represent important requirements for planned efficiency increases. By contrast, increased vertical integration allows for greater flexibility of manufacturing and a reduction of the time to market.

The study shows that about 50% of companies surveyed expect double-digit growth in revenues in the next five years solely. Eighteen percent of them even anticipate an increase in revenues of more than 20%. All in all, this results in an expected increase in revenues of 12.5% cumulated over five years. These are ambitious targets and interestingly, the expectation of SME’s do not differ from the estimate of large groups.

Noticeable is the comparison of the investment costs with the expected return revenue due to these investments. The investments costs in five years are higher in all sectors than the expected return revenue, illustrated in figure 6.4. The total investment costs is €140 billion while the return value is €110.1 billion. Interesting is the similarities between the different sectors, as can be seen in the same figure, the investment amount in percentage relative to their annual revenue are in the same order and every sector shows loss relative to their investment suggesting that the companies surveyed are willing to invest over a long time to finally make a profit.

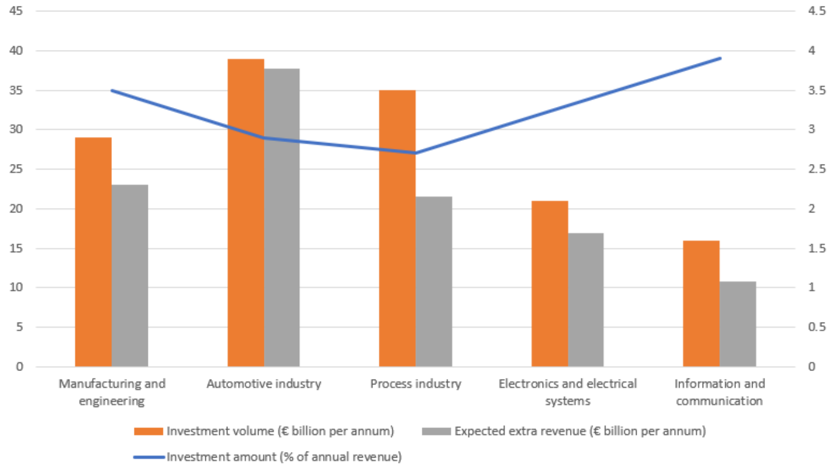


Figure 6.4: Investment costs compared with expected return revenue, own illustration based on the study [39]

6.4. Case studies

This section provides a summary of four case studies of Industry 4.0 in the manufacturing logistics conducted by Strandhagen [68]. The companies have been selected based on their stated goal of improving their internal flow of materials and general aim of improving their manufacturing logistics performance. The data on the case companies were obtained through two main approaches: a mapping of each company's production environment and a focus group survey. The case study distinguishes the result in four results, namely decision support, identification, information flow and automation and the key findings of each company is provided below.

6.4.1. Kleven

Kleven Maritime AS includes the two shipyards Kleven shipyard and Myklebust shipyard, both located on the west coast of Norway. Ship building at Kleven Maritime AS (from now Kleven) includes platform supply vessels, construction vessels, seismic vessels, and anchor-handling vessels. Production at Kleven is characterized by engineer-to-order production. Ships are designed and engineered in close collaboration with the customer, allowing a very high degree of customization. Production of ships requires a fixed position type of layout, where workers and materials are brought to the ship being produced. Compared to other types of layouts, the fixed position layout, which is common for shipbuilding and traditional engineer-to-order industries, is a factor for increasing the material flow complexity. This is also the case for Kleven.

Kleven focuses on modularization of products for achieving production efficiency. This means that ships are produced in modules, and then assembled into complete ships. The intention of this is to improve process control, production control and quality, and to reduce production lead times. Still, the typical throughput time is several months, up to 1–2 years. Naturally, the products produced by Kleven have a high product structure complexity, and a highly complex materials with several levels, as well as a number of sub-assemblies. Consequently, only a small number of ships are produced each year. Although Kleven is increasingly utilizing robots in the production, the manufacturing operations at Kleven are still mostly manual. The degree of automation and utilization of robots in the production is relatively low.

The survey response from Kleven indicates that the company has no specific opinion whether Industry 4.0 is a realistic goal for the company or not, and the company is only to a small extent investigating the specific opportunities of it. It is seen as neither a threat nor a possibility for the company in the future. Although, if pursued, it is to some extent expected to improve the manufacturing logistics of the company. The most important focus areas for the company today are standardizing products and components and reducing throughput times. Improving the flow of materials and applying better methods and principles for planning and control is somewhat important, while reducing work-in-process and inventories are not of any specific importance.

Decision support: To some extent, data collection from the production processes is used to analyze, monitor and control production today. An increase of this data collection, utilizing intelligent sensors and Auto

ID technology, is expected to have some improving impact on manufacturing logistics, although it is not an important part of the company's strategy for the future.

Identification: Implementing Auto ID technology such as RFID is not expected to improve the internal flow efficiency at Kleven's shipyard significantly. However, it is stated that Auto ID can be a means to increase integration with suppliers in the future.

Information flow: Today, Kleven has implemented an Enterprise resource planning (ERP) system. The current IT infrastructure is to some extent expected to be suited for transition to Industry 4.0. More integrated IT solutions are expected to have a great positive impact on the manufacturing logistics of the company. However, Kleven does not have any specific focus on using more of the functionality of the installed ERP system. On the other hand, there are clear future ambitions on making the yard operations more digitalized.

Automation: Kleven states that this category is the most relevant category for Industry 4.0 applications in manufacturing logistics. It is expected that 3D printing will be possible to implement in future operations. Moreover, over the last years, effort has been put into increasing the automation level and utilizing robots in production. For example some welding operations that previously were performed manually outside Norway now performed by robots at Kleven's shipyards in Norway. This is an enabler for maintaining production in Norway.

6.4.2. Brunvoll

Brunvoll AS develops and produces thruster systems for maneuvering and propulsion of several different types of advanced vessels. The company operates in a global market and is responsible for the whole thruster system. Business operations include design, production, sale and service. In addition to developing and producing new thruster systems, the after-sale market and service is an important part of the business for Brunvoll. This gives additional requirements in terms of spare parts production. By producing thruster systems for advanced vessels, the business is highly dependent on the shipbuilding industry, which the main customers represent. Production is based on a combination of an engineer to order and make to order strategy, where customization is allowed to a large extent. This gives a very high number of possible product variants. The shop floor layout is a combination of a fixed-position layout and cell layout, contributing to a high material flow complexity.

Brunvoll considers Industry 4.0 to be a realistic goal. However, the company has not put significant effort into investigating possible opportunities of it. From an overall perspective, it is by the company viewed as a slight opportunity for increasing competitiveness, although its impact on manufacturing logistics is only considered minor. The most important focus areas related to manufacturing logistics for Brunvoll are improving the flow of materials, reducing throughput time and inventories of raw materials and finished goods. Improving the methods and principles for planning and controlling production is part of this focus. Increasing the use of IT and integrating IT solutions are also issues to some extent, while standardization of products and components is considered less important.

Decision support: Data capture and analysis is only to a small extent used to monitor and control production at Brunvoll today. The logistics data that are collected include processing time, work-in-process, delivery time and reliability. The company to some extent agrees that improved data collection and analysis will improve the manufacturing logistics, and it is part of the production strategy for the coming years.

Identification: Implementing Auto ID is not expected to be applicable for improving the internal material flow efficiency in the factory significantly. However, the company states that product identification and especially product tracking can be a measure to increase integration with customers. Brunvoll expects that this will enable better integration of the value chain.

Information flow: Brunvoll has currently implemented an ERP system. In addition, implementing an MES system is under consideration. The company also expects that increased utilization and integration of IT systems will have major positive implications on manufacturing logistics, allowing more seamless flow of information. The company also states that there is a potential to utilize more of the functionality available in IT systems currently in place.

Automation: The use of additive manufacturing like 3D printing is highly relevant for Brunvoll as it is expected to be applicable to a large extent. Implementing such technology is also expected to contribute to reduced complexity related to manufacturing logistics to a large extent. Furthermore, the percentage of automated processes is expected to increase over the coming years, although not significantly.

6.4.3. Ekornes

Ekornes is a furniture production company.. They are positioned within the medium/high-end of furniture products, with the aim to be a leading actor and producer of branded goods within the home furniture industry, both in the national and international market. The company's most known product is the stress-less reclining chair, but sofas, coffee tables, etc., are also part of the product portfolio.

Ekornes has a strong focus on allowing customization of products. However, the customization is typically in terms of skin type and color of chairs. On the other hand, it gives a large number of possible product variants. To be able to deliver their products to customers efficiently, the company has employed a combination of make-to-order and assemble-to-order production strategy. The effect in reality is that finalization of products is done after customer orders have been received. When a customer order is received, with the specific customization in terms of skin type and color, the skin is cut and sewed before the chair is assembled.

Production is organized in a functional shop floor layout, with different departments responsible for each of the main production stages. One of the characteristics of the functional layout type is a complex material flow, although if seen on a higher level all products follow the same overall route through the different departments for each of the main production stages as.

Ekornes' survey response indicates that Industry 4.0 is a realistic goal and an opportunity for the company, but they have only to a certain extent investigated the possibilities and opportunities of it. It is stated that Industry 4.0 on a general basis will improve the manufacturing logistics in the company to a large extent. Improving the efficiency of the material flow is a major focus area of Ekornes. Mainly this is to be achieved by reduced through put time and increasing IT utilization.

Decision support: Today, Ekornes collects and captures large amounts of logistics data. These include throughput time, processing time, work-in-process, and delivery reliability. However, such data are not used for analysis in a large extent. On the other hand, the company believes that using such data for analysis will improve the manufacturing logistics of the company significantly.

Identification: The applicability of Auto ID technology like RFID in the production at Ekornes is considered high. However, the company states that implementation of Auto ID for product track and trace is believed to give only a moderate improvement in the flow efficiency of goods and material.

Information flow: Ekornes has today an ERP and MES system installed. Although projects have been initiated to investigate the possibilities for implementing both advanced planning model and product lifetime management systems. More integrated IT-systems can improve the manufacturing logistics to a large extent. In addition, there are functionalities of the current IT systems that are not utilized. However, the company has no specific focus related to increasing the IT system utilization.

Automation: Production technologies such as 3D printing are not expected to have any impact on the manufacturing logistics of Ekornes. On the other hand, the company expects that the level of automation and utilization of industrial robots will increase in the coming years.

6.4.4. Pipelife

Pipelife Norge AS is a part of the international Pipelife group. The group is headquartered in Austria, and is one of Europe's leading producers of plastic pipes. Pipelife Norge AS (from now Pipelife) is the Norwegian division of the group and produces plastic pipes in various areas, including water supply and sewage, heating ventilation and sanitation, cable protection, wiring and gas pipes.

Pipelife has an make-to-stock production strategy, with highly standardized and repetitive production of pipes in large quantities. Product variety and complexity of materials is low. Pipelife aims for cost advantage through economies of scale in their mass production of plastic pipes, and production is organized in a highly automated product line shop floor layout, with changeover times and set-up times being major factors for planning and control. In this layout, the material flow is very streamlined, with a low material flow complexity.

Pipelife's response on the survey indicates that the company sees Industry 4.0 as a very realistic goal. The company is also largely investigating possible applications. Furthermore, Industry 4.0 in general is considered as a great opportunity for the company, and is expected to improve manufacturing logistics significantly. To achieve more efficient internal logistics, improving the flow of materials and increasing IT-utilization are the primary focus areas of Pipelife, together with reducing changeover times. Finding better methods and principles for planning and control and reducing inventories of raw materials and finished goods are also of a certain importance. Standardization of components, increasing flexibility and reducing work-in-process are less important focus areas.

Decision support: Production data is captured and analyzed at Pipelife today, and the company states that this will be increasingly important for improving manufacturing logistics in the future. Over the last three years, the quality of information available has improved significantly, but information is only to some extent accurate, timely and available for use. The sharing efficiency is also moderate. However, the company now has a strong focus on applying real-time capture and analysis of information for decision support and improving manufacturing logistics performance.

Identification: Implementation of Auto ID is expected to be highly applicable for Pipelife, and it is expected to give significant improvements to manufacturing logistics performance. Auto ID technology such as RFID is expected to be applicable for improving production planning and control activities, purchasing and inventory control.

Information flow: Pipelife has today implemented an ERP system and an MES system, and the current IT infrastructure is expected to be well suited for transition to Industry 4.0. Pipelife also states that more integrated IT solutions will have a positive impact on the manufacturing logistics of the company. On the other hand, Pipelife has to a large extent a focus on increasing the current IT utilization to apply more of the available functionality.

Automation: Production technologies such as 3D printing are not considered relevant for Pipelife. On the other hand, a large amount of the production processes are already automated. This, as well as the level of autonomy, is expected to increase over the next years.

6.5. Conclusion

The implementation of Industry 4.0 and Logistics 4.0 solutions requires several years and a lot of investment but results in significant changes to the value chain. Companies have to recognize the importance of the implementation whereby it is necessary for the management to place it to a high priority level.

According to the study with 235 German companies, companies in all sectors have recognized the importance. The key findings of this study showed that in 2020 more than 80% of the companies will have digitized their value chains obtaining an increase in efficiency of 18%. The companies surveyed will invest 3.3% of their annual revenues which is equivalent to €140 billion annually and nearly 50% of their total capital investments. They expect to generate an additional €110 billion revenue in total per year. The increase in horizontal and vertical integration will result in better planning and control in manufacturing and logistics, higher customer satisfaction and greater flexibility in manufacturing.

Important note is that the study is conducted in Germany. There is no other study found which elaborates the state of Industry 4.0 or Logistics 4.0 on such scale.

Strandhagen [68] concluded that the case companies investigated in this study indicate that companies with low degree of production repetitiveness, high material flow complexity and high degree of engineer-to-order production are least suited for a transition to Industry 4.0 in terms of manufacturing logistics. In addition, these companies seem to be less enthusiastic of Industry 4.0. Companies with a higher degree of production repetitiveness, lower material flow complexity and lower degree of engineer-to-order production seem, in comparison, to be less challenged by the production environment. Moreover, they are more actively investigating the possibilities Industry 4.0 technologies can offer. Further research should include more detailed investigations of how Industry 4.0 technologies can be applied in manufacturing logistics and where in the logistics system each technology application is most relevant. Moreover, a similar, larger scale survey should be conducted to further investigate the relationship between production environments and the potential applications of the Industry 4.0 technologies.

7

Conclusion

The vision of Industry 4.0 is to create a ubiquitous connection between people, things and machines which is focused on creating smart products, procedures and processes. These smarts products and services main feature is to communicate and have knowledge to make accurate and deliberate decisions for the desired next step for production while taken into account the current state of all elements and the companies' business model.

There are four main components which enables the theory of Industry 4.0. CPS are systems which integrate physical processes into the cyberspace making it possible to digital follow the physical processes. IoT is a global network infrastructure accessible for an overall interconnection between all objects in which interoperable communication is possible. IoS is based on IoT and enables service vendors to offer their services via the internet making it possible to reach to consumers via various channels. Smart factories integrates the above components and is the system in which every component is interconnected, making it possible for products to find their way independently through production processes and are easily identifiable and locatable at any time, pursuing the idea of a cost-efficient, yet highly flexible and individualized mass production. Smart factories will make the increasing complexity of manufacturing processes manageable. Hereby, the main challenge is to acquire sufficient IT skills to rapidly implement the technologies on a widespread basis which is inseparable with high investments costs.

Logistics 4.0 is a more specific term than Industry 4.0, as it specifies on the logistics systems of a business while Industry 4.0 takes the whole into account. The vision of Logistics 4.0 is to enlarge the efficiency and performance of a logistics systems by adapting high-tech technologies. This will result into an ILS, instead of a smart factory for Industry 4.0, which creates an interconnection between all elements within the system with the use of CPS, IoT and IoS. The ILS is a logistics system in which real-time data-transfer, communication and predictions of the future for the whole system is possible. This results into a system which can operate autonomously by making decentralized decisions while taking into account the current status of all elements in the system, business model of the company, connection with business partners and the predicted future.

This vision can be achieved by improving the component of the logistics system. The main components of an integrated ILS require autonomous logistics, product intelligence, intelligent transportation systems, intelligent cargo and self-organizing logistics. Hereby, the strategy to achieve the objectives of Logistics 4.0 is equal to Industry 4.0: to create a connection between all components within the logistics system with products which are end-to-end designed for this function while maintain a high co-operation with logistics systems from other businesses.

The technologies CPS, IoT and IoS are currently theoretical technology concepts, which therefore, are intangible and hard to work with for a technology supplier and, especially, technology user. Hence, a practical reflection of these concepts is attributed as smart objects. The smart object is the central technology which embeds CPS, IoT and IoS. The collaboration of multiple smart objects can result in a smart factory for Industry 4.0 and an ILS for Logistics 4.0. Smart objects consist of several hardware-based and software-based technological configurations.

The hardware-based technologies enable functions as automatic identification and localization, M2M communication, energy supply, sensing and actuating, data and information processing and Human-machine interaction. These functions are proven to be important to the essence of Logistics 4.0. The software-based technologies enable slightly different functions for smart objects, namely AI, autonomy of action, advanced data analytics and digital integration platforms. The software-based technologies predominantly are used to enhance the functionality of information-processing unit of smart objects.

A structured combination of the hardware-based and software-based technologies can provide solutions for the logistics system. The combinations translates the interconnection of these technology disciplines and makes them implementable. The decision of which identified technologies are used to form an smart object is strongly dependent on its usage and its application. For logistics systems, the solutions can be translated into an highly-effective transport system capable of communicating with the controlling entity and implementable in an ILS.

The implementation of Logistics 4.0 requires a lot of structure. In order to make an autonomous logistics system, there is necessity of an hierarchical structure in all components of the system. An hierarchical structure provides a logical order of elements in which higher placed elements have more authority. Such structures are commonly described in literature and provide a guidance with the implementation of Logistics 4.0. These structures have an hierarchical format in which higher placed levels have more authority. Each structure has a slightly different approach which provide guidance for, for example, a functional CPS or a business-orientated ILS.

For the measurement of the implementation of Logistics 4.0 of a business, a scale of implementation is provided. The scale provides the possibility to measure the core values of Logistics 4.0. Based on this scale, a business can reflect on each core value and can obtain knowledge to reach an higher level of implementation. The scale provides measurement tools for the automation of transport, identification, interconnectivity, autonomous decision-making and flexibility and adaptability. An important side-note is that the efficiency of the scale is not yet proven.

The implementation of Industry 4.0 and Logistics 4.0 solutions requires several years and a lot of investment but results in significant changes to the value chain. Companies have to recognize the importance of the implementation whereby it is necessary for the management to place it to a high priority level.

According to a large scale study in Germany, companies in all sectors have recognized the importance of Industry 4.0. The key findings showed that in 2020 more than one fourth of the companies have digitized their value chains to obtain an increase in efficiency of 18%. The companies surveyed will invest nearly 50% of their capital investments into Industry 4.0 solutions and expect to generate an extra revenue of an equal amount. The increase in horizontal and vertical integration will result in better planning and control in manufacturing and logistics, higher customer satisfaction and greater flexibility in manufacturing.

A performed case study of the current state of Industry 4.0 in the manufacturing logistics of four companies indicated that companies with low degree of production repetitiveness, high material flow complexity and high degree of engineer-to-order production are least suited for a transition to Industry 4.0 in terms of manufacturing logistics. In addition, these companies seem to be less enthusiastic of Industry 4.0. Companies with a higher degree of production repetitiveness, lower material flow complexity and lower degree of engineer-to-order production seem, in comparison, to be less challenged by the production environment. Moreover, they are more actively investigating the possibilities Industry 4.0 technologies can offer. Further research should include more detailed investigations of how Industry 4.0 technologies can be applied in manufacturing logistics and where in the logistics system each technology application is most relevant.

8

Discussion

The objective of this paper was to provide a comprehensive overview of Logistics 4.0 which a non-expert reader provides with enough information to have full understanding of the concept with more in-depth information regarding the technologies, implementation and the current state.

To my opinion Chapter 2 *The state of the art of Industry 4.0* provides the background information for Logistics 4.0 in a structured and understandable manner. This was more difficult for *Chapter 3 The state of the art of Logistics 4.0* due to that Logistics 4.0 is a relatively new concept in comparison with Industry 4.0 and as Logistics 4.0 is a massive subject, the profound information for the applied technologies is limited. First it was necessary to describe the basic technologies of Logistics 4.0, followed by the technologies component of smart objects. Due to the magnitude of functionalities of smart objects, it was not possible to thoroughly investigate all functionalities in-depth. For example, it would be interesting to practice an entire literature assignment regarding RFID systems. *Chapter 5 Implementation* provided several structures to implement the most important components of Logistics 4.0. Since every business should be analyzed personally to specify exact implementation steps, the provided structure are universal. *Chapter 6 Current state* elaborates the only large scale study of the current state of Industry 4.0 which was conducted in Germany. The current state of Logistics 4.0 is hard to capture due to the relatively new concept, closely related to Industry 4.0 and it requires a lot of insights in multiple companies making it almost impossible to conduct this without an provided large scale study. Assumed is that this conducted study in Germany regarding Industry 4.0 corresponds to the current state of Logistics 4.0 in whole Europe.

As Logistics 4.0 is a relatively new concept and so close related to Industry 4.0, it was sometimes hard to find literature which was specified on Logistics 4.0. This resulted into filtered information of Industry 4.0 as this theory also affected the logistics systems of a business. And Logistics 4.0 is an enormous subject to make an overview with profound information regarding all elements of the subject. Hence, the profound information can be limited. However, to my opinion, an comprehensive overview is provided which is understandable for non-expert. The subject is extremely interesting and further research is exceptionally relevant for the current logistics. My recommendations for further literature and research assignments would be:

- Specific smart object related functionalities, with titles such as *The identification technologies of smart objects in a manufacturing process* or *M2M communication in the logistics system.*
- Specific implementation steps for specific business, with a title such as *The approach for manufacturing companies to implement Logistics 4.0.*

These examples for further research would be an extension for this paper and interesting for other TEL students to investigate for their literature or research assignment.

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