BUSINESS PROCESS QUALITY COMPUTATION

Computing Non-Functional Requirements to Improve Business Processes

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Technische Universiteit Delft

BUSINESS PROCESS QUALITY COMPUTATION

Proefschrift

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To Moritz
Whose presence brings me to heaven.

To Haleh
Who is an angel.

To My Parents
Who are pure love.

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If you treat an individual as she is,
she will remain how she is.
But if you treat her as if she were what she ought to be and could be,
she will become what she ought to be and could be.
-Johann Wolfgang von Goethe

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Summary

Business process modelling is an important part of system design. When designing or redesigning a business process, stakeholders specify, negotiate, and agree on business requirements to be satisfied, including non-functional requirements that concern the quality of the business process. This thesis addresses the question of how to specify and compute the quality of a business process, given the model that stakeholders use.

The motivation for this thesis is the increasing importance of the quality of business processes. Knowing the quality of specific business processes enables stakeholders to judge if these processes need improvement. Knowing the quality of the constructs of those processes (viz., events, inputs, activities, and outputs) and the way they are structured enables a more detailed analysis of their shortcomings and provides a basis for the design of improvements.

The research challenge of this thesis is grounded in the assumption that: "Organisations need an appropriate means to effectively compute achievement of their goals and objectives by their business processes." Given this challenge, the main research question on which this thesis focuses is: "Can the quality of a business process be computed quantitatively at different levels of granularity?" The research objective is: *"To develop frameworks, factors, and metrics for computing non-functional requirements (quality) of business processes quantitatively at different levels of granularity."*

The outcomes of this thesis are:

1) BPIMM, a language-independent business process integrating meta-model, based on the concepts of seven mainstream business process modelling languages: BPMN, EPC, RAD, UML AD, SADT, IDEF0, and IDEF3.

2) BPC-QC (Business Process Concept - Quality Computation), an approach to quality computation at the lowest level of granularity of a business process. The approach consists of:

    i. BPC-QEF (Business Process Concept - Quality Evaluation Framework), a language-independent generic framework and algorithm to compute the quality of the constructs of a business process: event, input, activity, and output.

    ii. A set of business process quality dimensions and factors. The following quality dimensions are distinguished: performance, efficiency, reliability, recoverability, permissibility, and availability. Each dimension

categorises different quality aspects in terms of factors. A non-exhaustive set of sixteen quantitative factors is provided.

iii. Quality metrics for each of the quality factors, to facilitate a quantitative computation of the quality of a specific construct of a business process.

3) BP-QC (Business Process - Quality Computation), an approach to compute the quality at the highest level of granularity of a business process. The approach consists of:

   i. BP-CQCF (Business Process - Compositional Quality Computation Framework), a language-independent generic framework and algorithm to compute the quality of a business process as a whole, given the quality of its constructs.

   ii. A set of generic business process modelling patterns to decompose a business process into more succinct parts, namely: sequential, parallel with synchronisation, exclusive, inclusive, simple loop, and complex loop.

   iii. A set of over one hundred computational formulae. For each combination of modelling pattern and a quality factor, there is a formula to compute the quality.

4) AAV (Approach to Application and Validation), an evaluation plan to evaluate BPIMM, BPC-QC and BP-QC in practice, together with expert stakeholders. The plan consists of the units of measure, a measurement model, and a case study procedure.

To evaluate the applicability of the contributions of this thesis to real world business needs, four case studies have been conducted in different environments: a Dutch educational institution, a global financial institution, an international financial service provider, and a Dutch research project on crisis management. Each of these case studies concerns a different, single business process.

This thesis shows that:

1) A quality computation approach can be adopted independent of a business process modelling language.

2) Quantitative quality factors can be introduced specifically for the constructs of a business process.

3) Quantitative metrics and computational formulae can be developed for specific quality factors, allowing the computation of different aspects of the quality of a business process quantitatively at different levels of granularity.

4) An evaluation plan can be developed to evaluate the applicability of the contributions of this thesis (viz., BPIMM, BPC-QC, and BP-QC).

The contributions of this thesis are designed to be beneficial to the areas of business and management, requirements engineering, software engineering, and business process modelling. In the areas of requirements engineering and software engineering, these contributions are intended to help practitioners to consider non-functional requirements at the earliest stage. In the area of business process modelling, information systems, service computing, and cloud computing, the contributions can be used for quality-driven modelling, design, and redesign. To conclude, knowing the quality value of a business process at different levels of granularity provides a basis for its improvement.

Table of contents

Table of Figures

List of Tables

Part I:
Introduction

Chapter 1. Introduction

In all science,
error precedes the truth,
and it is better it should go first than last.
-Hugh Walpole

1.1. Introduction

Businesses are getting increasingly complex due to many facets: new technologies are changing the way people interact with each other and with businesses; the business environment and customer requirements are changing and consequently the goals and the objectives organisations strive to achieve. There is a need for understanding the businesses in order to manage them, to cope with these changes, and to be able to improve them to be more efficient and effective.

Understanding a business is a challenging task. One way to understand a business is through describing them in terms of its business processes. A business process is a set of structured activities that takes a set of inputs and produces a set of outputs to serve a particular goal. One or multiple actors (i.e., executors) can be involved in the enactment of a business process. Their role and their interactions with each other should be recognised. In general, business processes indicate operations carried out to achieve a certain goal. The way activities, decisions, and actors are structured and organised to run a business process has direct impact on their efficiency and effectiveness and consequently on attaining their business objective.

Business processes have a direct impact on cost and revenue generation of an organisation. Thus, business processes are assets of an organisation that must be captured and improved to contribute to the organisation's goals and objectives. Business process management (BPM) provides *"the big picture,"* promoting business efficiency and effectiveness while striving for innovation, flexibility, and integration of the technology. The starting point in BPM is business process modelling. Business process modelling represents a business process capturing the structure of the constituting activities, the actors involved in the execution, inputs required, events and decisions affecting the flow, and expected outputs.

Upon this representation (i.e., abstraction), the business processes can be captured, understood, executed, automated, evaluated, re-engineered, and improved.

Through applying a process-oriented structure, organisations become more flexible toward the dynamic environment in comparison to a functional hierarchy. Business process modelling plays a key role in establishing a process-oriented environment, culture, and technology (Luo and Tung, 1999). Business process modelling contributes to quality in software development, software maintenance, and integrated information systems.

High quality business processes are paramount to the performance of an organisation and achieving its goal. Nowadays, this need is acknowledged more and more by the organisations. Business process management as a science is focusing on improving an organisation performance via managing and optimizing the organisation's business processes. In this context, the thesis aims to contribute to business process improvement and consequently business improvement through introducing an approach for quantitatively computing quality of business processes and its constituent elements considering stakeholders requirements.

The remainder of this chapter is structured as follows. Section 1.2 discusses the research motivation, and Section 1.3 presents and discusses the research questions. Section 1.4 elaborates on the research deliverables, and Section 1.5 presents the research assumptions. Section 1.6 describes the research method, and Section 1.7 presents the structure of the thesis. Section 1.8 provides a summary of the chapter.

1.2. Research Motivation

An organisation's performance depends upon the collective ability of its business processes to achieve its fundamental objectives (Shaw et al., 2007). More and more evidence is found showing the strategic value of processes (Willaert et al., 2007). (McCormack and Johnson, 2001) finds that companies with strong signs of business process orientation also perform better both from an internal perspective and a resultant perspective. Business process orientation has been shown to reduce inter-functional conflict and increase interdepartmental connectedness and integration, both of which impact long and short-term performance.

Through an empirical research, (Willaert et al., 2007) shows that being process-oriented is a matter of mastering a whole range of techniques and principles in order to improve business processes and organisational performance. The study shows that process performance characteristics are positively related to the degree of business process orientations in an organisation. This thesis assumes that knowledge about the quality of business processes is core to an organisation's success. However, evaluating the quality of a business process is not a straightforward task. Different stakeholders such as managers, modellers, and software engineers require a shared understanding of the meaning of quality (Kedad and Loucopoulos, 2011). Quality criteria and evaluation methods are needed to assist in this process (Kedad and Loucopoulos, 2011). Therefore, studying the quality of business processes is a timely and important research undertaking. In this thesis, the notion of quality refers to distinctive characteristics in (potential) business process execution and its constituent elements to fulfil non-functional requirements of stakeholders.

Requirements are normally classified into functional requirements, for short FRs, and non-functional requirements, for short NFRs, also known as quality requirements, for short QRs. This classification is fuzzy and depends on three facets of kind, satisfaction, and representation (Glinz, 2005). FRs of a business process refer to the ability of a business process to deliver qualified products and services as well as the ability of the outcome to fulfil its functional expectations (Loucopoulos and Champion, 1989). (Glinz, 2007) proposes a set of classification rules to distinguish FRs and QRs in systems engineering. In this classification, QRs are defined as requirements about timing, processing or reaction speed, input volume or throughput (i.e. performance requirements) as well as specific qualities of a business process reflected in those terms ending in " –ility" namely: reliability, security, availability, etc. This thesis adheres to the definition of QRs by (Glinz, 2007).

(Adam et al., 2009) argues that, even though quality plays a central role in business process management, systematic consideration of quality requirements is still missing. They claim that in the world of business process management, quality alignment is not addressed sufficiently. (Heravizadeh et al., 2008) supports this position claiming that in Business Process Modelling and design, the quality dimension of a business process is often neglected. (Pavlovski and Zou, 2008) states that NFRs are dealt with in a less rigourous manner in comparison to the comprehensive coverage of functional characteristics of the business.

The motivation for this thesis is the increasing importance of quality in different areas such as service computing (where business processes ensuring the service quality are often the differentiating factor between candidate services) and cloud computing (where business processes for the compliance of stored data is a significant factor). In addition, measuring the quality of an individual concept of a business process (i.e., business process constructs such as activity, input, etc.) provides insights with which to improve the overall quality of a business process. According to this view, quality of a business process should be computed at different levels of granularity, from business process concepts (e.g., activities and input) at the lowest level, to business process parts at intermediate levels, and to the business process as a whole at the highest level.

1.3. Research Questions

The research challenge addressed in this thesis is defined as follows: "Organisations need an appropriate means to effectively compute achievement of their non-functional goals and objectives by their business processes." Given this research problem, the accompanying managerial question reads as follows: "Can the quality of a business process be quantitatively computed at different levels of granularity?" This research question is subdivided into more detailed questions, as shown in Figure 1.

Representation of a business process through deploying a modelling language provides a formal expression of business processes, which fosters mutual understanding and comprehension of business processes between different stakeholders. For this reason, understanding the concepts of different business process modelling languages is necessary. This is reflected in research question A: "Can the concepts of mainstream business process modelling approaches be identified?" The plethora of different business process modelling languages, however, presents a dilemma regarding the utility of the quality framework. Although there are trends pointing towards standardisation (e.g. (White, 2004)), there is still a long way before reaching the state of a standard business process modelling language. There are practical situations where a common approach is neither feasible nor desirable; for example, in inter-enterprise integration efforts, where different approaches and cultures may co-exist, it is usually the case that business process modelling languages (BPMLs) are used according to local practices. One of the objectives of this thesis is to be independent of any BPML. This is achieved by viewing quality through a lens that focuses on the semantics of the application rather than the syntax of the BPML used to describe the application, while presenting a language-independent abstraction of business process concepts. The goal is the development of a "Business Process Integrating Meta-Model: BPIMM" as an abstraction of the integration of mainstream business process concepts. The proposed generic meta-model is designed considering seven mainstream business process modelling languages (BPMN, IDEF0, IDEF3, RAD, UML-AD, SADT, and EPC).

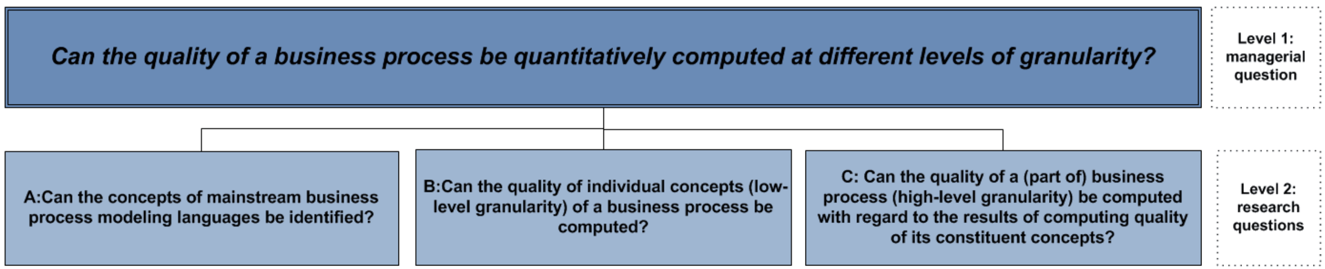

Figure 1 Research questions

Computation of the quality of business processes at different levels of granularity calls for suitable mechanisms and means. The quality can be computed at the lowest level of granularity, which is the individual business process concepts level (e.g. activity, input, etc.), or at higher levels, such as business process parts of the whole business process. Research question B: “Can the quality of individual concepts of a business process be computed?”. Quality can be computed for quality factors as an inherent property of a business process concept. Being able to compute different quality factors for the individual concepts of a business process calls for metrics enabling the computation. Therefore, a set of quality metrics is developed, based on areas such as quality of service, business and management, and software engineering for the purpose of computation. Moreover, a Business Process Concept Quality Evaluation Framework (BPC-QEF) and an accompanying algorithm are designed to help modellers and evaluators to conduct the computation in a systematic and generic manner. In addition to individual concepts, there is a need for computing the quality of a business process or a part of it based on the results of evaluating the quality of its constituent concepts. This need is reflected in research question C: “Can the quality of a (part of) business process be computed on the basis of the results of computing the quality of its constituent concepts?” The research objective is grounded on the assumption of being able to decompose a given business process model into distinct parts. Answering these questions results in a framework (BP-CQCF), an algorithm, a set of generic patterns, and computational formulae.

1.4. Research Deliverables

Figure 2 depicts the research questions in boxes and their corresponding research deliverables in ovals. For each research question, there is a chapter dedicated to its answer. To summarise, this thesis aims to address the following research deliverables:

1) BPIMM is a language-independent business process integrating meta-model, based on the concepts of seven mainstream business process modelling languages: BPMN, EPC, RAD, UML-AD, SADT, IDEF0, and IDEF3. The meta-model provides the basis with which to identify the business process concepts and their relationships for computational purposes.

2) BPC-QC (Business Process Concept - Quality Computation) is an approach to quality computation at the lowest level of granularity of a business process. The approach consists of:

    i. BPC-QEF (Business Process Concept - Quality Evaluation Framework): A language-independent generic framework and algorithm to compute the quality of the concepts of a business process: event, input, activity, and output.

ii. A set of business process quality dimensions and factors. The following quality dimensions are distinguished: performance, efficiency, reliability, recoverability, permissibility, and availability. Each dimension categorises different quality aspects in terms of factors. A non-exhaustive set of sixteen quantitative factors is provided. These factors intend to facilitate the quantitative evaluation of QRs and the degree to which QRs related to business process concepts are satisfied.

iii. Quality metrics for each of the quality factors, to facilitate a quantitative computation of the quality of a specific concept of a business process.

3) BP-QC (Business Process - Quality Computation), is an approach to compute the quality of a business process at the highest level of granularity. The approach consists of:

i. BP-CQCF (Business Process - Compositional Quality Computation Framework): A language-independent generic framework and algorithm to compute the quality of a business process as a whole, given the quality of its concepts.

ii. A set of generic business process modelling patterns to decompose a business process into more succinct parts, namely: sequential, parallel with synchronisation, exclusive, inclusive, simple loop, and complex loop.

iii. A set of more than 150 computational formulae. For each combination of modelling pattern and quality factor, there is a formula to compute the quality.

Frameworks and algorithms for different levels of granularity are intended to assist business process modellers and analysts to work in a systematic and generic manner when including quality factors in their BPM activities. The contribution of these frameworks and algorithms are the establishment of a set of conceptual structures and method steps that are independent of any particular modelling language being used. The frameworks are not confined to any class of applications and designed to have a wide range of applicability.

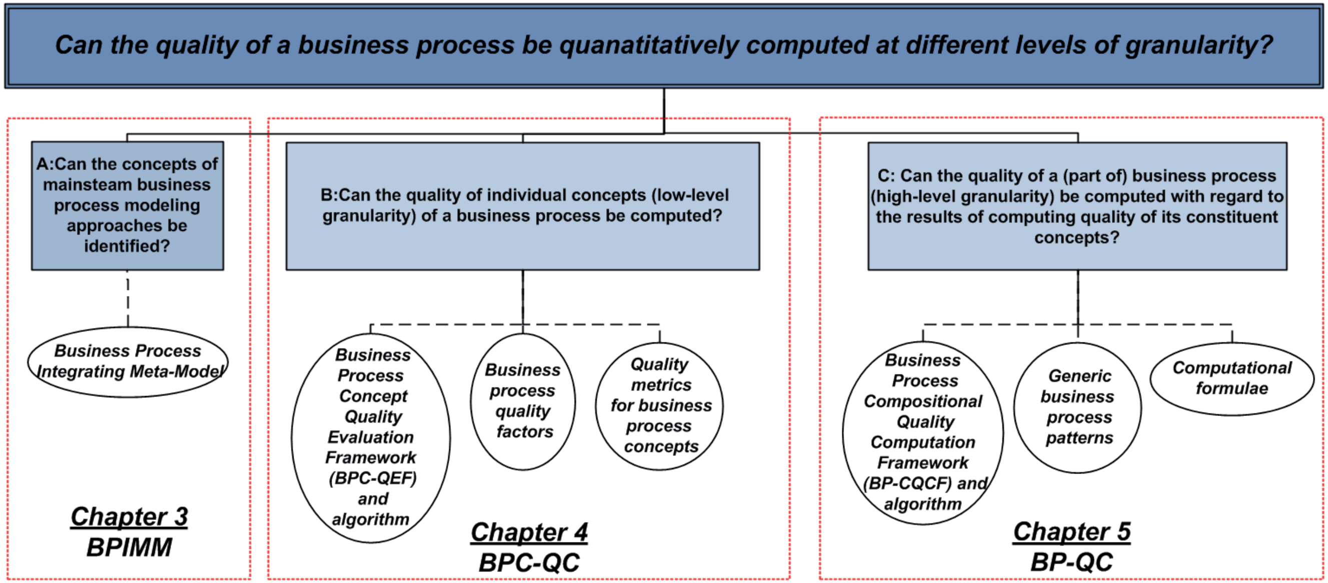

Figure 2 The research questions and their corresponding deliverables

Figure 3 depicts a positioning of quality computation in a model-driven architecture (Bézivin, 2005). As can be seen, estimation takes place at the model-level (business process type level) where the required data are estimated. At the runtime/data level (business process instance level), measurement takes place where required data are acquired through observation.

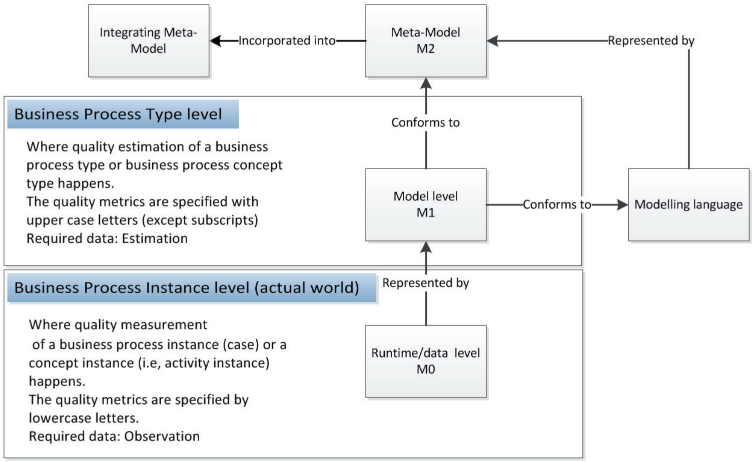

Figure 3 Positioning quality computation in a model driven architecture

An example is provided in Figure 4.

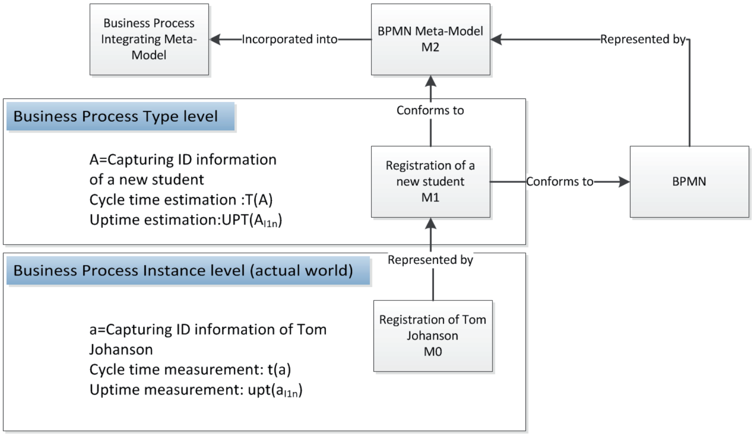

Figure 4 Quality computation in a model driven architecture (an example)

The research questions drive the thesis and lead to the research method and design. Section 1.6 discusses and justifies the research design of this thesis.

1.5. Research Assumptions

In the context of this thesis, it is assumed:

1. That a business process can be modelled by means of a business process modelling language (BPML) that enables computing the quality of the business process in terms of different quality dimensions*.
2. That a business process model represents an agreed definition of a business process and that all models are well formed. In other words, models are the medium of the computation*.
3. That the required data for computation is available. The real values for measurement are captured from the actual executions of business processes and probabilities and figured values are utilised for estimation purposes**.
4. That the quality of a business process can be defined as a function of the quality of its constituent parts. This requires that a business process can be decomposed into distinct parts, on the basis of a set of predefined patterns, and that the quality values of the constituent parts of a business process can be accessed.

* The thesis considers that a "business process is represented by a model". Whilst some authors pay attention to the quality of the model per se (de Oca et al., 2015, Guceglioglu and Demirors, 2005, Vanderfeesten et al., 2007, Cardoso, 2007), the thesis assumes that the model is a well-formed model (i.e., complete, syntactically and semantically correct) and agreed upon by the stakeholders.

** The real values for measurement purposes are captured from the executions of a business process through implementing techniques such as process mining. All process mining techniques assume that events can be sequentially recorded such that each event refers to an activity and is related to a process instance. Event logs can store additional information such as the actor (person or device) executing or initiating an activity, an event's time stamp, or data elements recorded with an event (van der Aalst and Dustdar, 2012). For estimation purposes, probabilities and figured values are utilised.

1.6. Research Method

This section describes the philosophical foundation and research design applicable to this thesis.

1.6.1. Philosophical Positioning

Science is the rational search for new or improved knowledge (Wieringa et al., 2002). This is reflected in two interdependent philosophical considerations, namely ontology and epistemology, relates to the nature of reality and knowledge (Figure 5). The philosophical basis of the research acts as a guide for choosing an appropriate research method.

- Ontological positioning

Ontology refers to the nature of the reality (Klein, 1996). Four major paradigms of realism, critical realism, pragmatic realism and idealism are recognised for ontological positioning(Lachs and Talisse, 2008). Realism expresses the ontological assumption that the world has an objective existence (Frank, 2006) and assumes that merely there is some sort of reality independent of the observer (Emory, 1985). With respect to its epistemological meaning, pragmatic and critical realism can be differentiated. Pragmatic realism assumes that the world is perceived as it is, whereas critical realism claims that the perception of reality is limited and deceptive. Critical realism indicates the need to carefully analyse possible sources of bias. Idealism assumes that reality is an idealistic construction: our perception is determined by our ideas (Frank, 2006).

The ontological paradigm chosen for this thesis is critical realist. Furthermore, claims about reality are subjected to critical examination to facilitate apprehending the reality as closely as possible (Guba and Lincoln, 1994).

- Epistemological positioning

Epistemology is the branch of philosophy concerned with the nature and scope of knowledge (Klein, 1996). Three major epistemological paradigms are recognised, namely positivism, post-positivism, and interpretivisim.

The basic ontological assumption underpinning the positivist tradition is that reality is objectively given and that it can be described independently from the researcher. The role of scientific research is thus to systematically acquire objective knowledge about the phenomena known to exist in this reality. This assumption is described by (Popper, 1963) stating that positivism assumes that the truth is manifest, sometimes clearly present, sometimes 'covered', but always waiting to be literally 'discovered' by the researcher. Positivists believe that all knowledge about reality is objectively given and an observer is capable of studying it without influencing it (Guba and Lincoln, 1994). However, this assumption is problematic. First, in the case of a simple individual observation of reality, there is no guarantee that the image that perception of reality actually corresponds with reality, as to verify this, a comparison of this image of reality with reality itself is needed, but reality can only be accessed itself through perception. Second, even if a perception provides an accurate account of a possible reality, the work of philosophers such as (Kant, 1781) shows that there is a limit to what can be perceived. The fact that science is constantly developing more sophisticated measurement and observation instruments to extend this limit, in fact, proves its existence. Kant distinguishes between the phenomenal worlds, the world of what can be perceived from objects, and the nominal world, the world that consists of things *an sich*, that is, that what remains when an object is stripped of all its perceivable attributes; there is no access to this world.

The interpretivist tradition addresses the problems concerning the reliability of perceptions by being more moderate in their claims. The basic ontological assumption underpinning the interpretivist tradition is that the perception and interpretation of a possible reality cannot be separated from the researcher. Knowledge is seen as a subject-dependent interpretation of phenomena in reality. As opposed to positivism, it does not take reality as a starting point, but subject-dependent perception and interpretations of it.

While positivists believe that the researcher and the researched person are independent of each other, post-positivists accept that theories, background, knowledge and values of the researcher can influence what is observed. However, like positivists, post-positivists pursue objectivity by recognising the possible effects of biases. Post-positivists relax the philosophical assumptions of positivism (Shanks, 2007) and believe that a reality exists, like positivists do, though they believe it can be known only imperfectly and probabilistically (Robson, 2002b). (Guba and Lincoln, 1994) adds the following three amendments to the dimensions of positivism in defining post-positivism:

- An objective reality is imperfectly knowable (critical realist ontological position).
- A subjective researcher can only know about reality to a degree of probability (modified dualist epistemological position).
- A modified experimental method is used including hypothesis refutation, using both quantitative and qualitative methods (modified experimental methodological position).

This thesis is based on the appreciation that reality can only be imperfect and incomplete. While independent observers can agree upon reality, it is respectful of relativity. Therefore, from an epistemological point of view, the thesis is positioned as post-positivist.

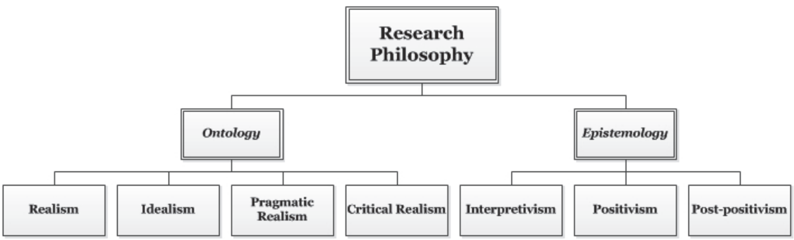

Figure 5 Research paradigms from the ontological, epistemological and methodological point of view

On the basis of the ontological and epistemological position of the thesis, the next section describes and justifies the research method developed in this thesis.

1.6.2. Research Methods

Most research in the Information Systems (IS) discipline is characterised by two paradigms: design science and behavioural science (Peffers et al., 2007, Hevner et al., 2004). Different research methods -especially from different paradigms- focus on different aspects of reality to provide a richer understanding of a research topic by combining several methods (Mingers, 2001, Hevner et al., 2004, Frank, 2006).

Design is both a process (a set of activities) and a product (artefact)- a verb and a noun. The platonic view of design supports a problem-solving paradigm that continuously shifts perspective between design processes and designed artefacts for the same complex problem. Design-science is a research paradigm that extends the boundaries of human and organisational capabilities by creating new and innovative artefacts. Artefacts are innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, and use of information systems can be effectively and efficiently accomplished (Tsichritzis, 1998). IT artefacts are broadly categorised as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototyped systems) (Hevner et al., 2004).

It is incumbent upon researchers to further knowledge that aids in the productive application of information technology to human organisations and their management (Hevner et al., 2004). Acquiring such knowledge involves two complementary, but distinct paradigms: behavioural science and design science (March and Smith, 1995). The behavioural science paradigm seeks to develop and justify theories (i.e., principles and laws) that explain or predict organisational and human phenomena surrounding the analysis, design, implementation, management, and use of information systems. The goal of behavioural science research is truth and the goal of design science research is utility (Hevner et al., 2004). Truth informs design and utility informs theory. On one hand, the theories justified/developed by behavioural science impact, and are impacted by design decisions. On the other hand, the artefacts developed by design science must be evaluated with respect to their utility in practice. An IT artefact, implemented in an organisational context, is often the object of study in IS behavioural science research. Much of this behavioural research focuses on one class of artefact, the instantiation (case study as an empirical validation method in this thesis) (Hevner et al., 2004).

Philosophically, these statements draw from the pragmatists (Aboulafia, 1991), mentioning that truth (justified theory) and utility (artefacts that are effective) are two sides of the same coin and that scientific research should be evaluated in the light of its practical implications.

This calls for synergistic efforts between behavioural-science approach and design science approach in information systems. The key insight here is that there is a complementary research cycle between the design science and behavioural science to address fundamental problems faced in the productive application of information technology Figure 6 (Hevner and Chatterjee, 2010).

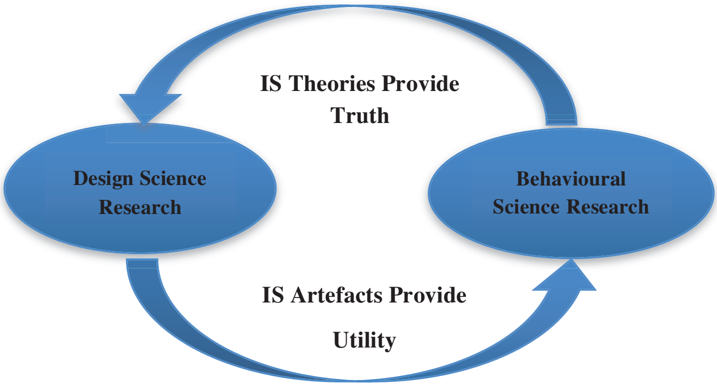

Figure 6 Complementary natures of design and behavioural science research (Hevner and Chatterjee, 2010)

This thesis follows a multi-method approach based on design science research and behavioural science research. A detailed discussion of the research design is offered in the following sub-section.

1.6.3. The Research Design

The research design for this thesis is influenced by the research framework proposed by (Hevner et al., 2004), based on both behavioural science and design science paradigms. According to this framework, the contributions of design science and behavioural science in IS research are assessed by (1) applying them to the business needs in an appropriate environment, and (2) evaluating their value for further research and practice as an addition to the current knowledge base.

Three design science research cycles are: relevance cycle, design cycle and rigour cycle (Hevner and Chatterjee, 2010) (Figure 7). The relevance cycle bridges the contextual environment of the research project with the design science activities. The rigour cycle connects design science activities with the knowledge base of scientific foundations, experience, and expertise that informs the research project. The central design cycle iterates between the core activities of building and evaluating the design artefacts and processes of the research.

The problem of rigour and relevance is originally introduced by (Schön, 1983) defining "technical rationality" as a problem-solving approach in which possible alternative solutions are compared with respect to goals, before one solution is selected to be implemented. He identifies three assumptions about the problem made by technical rationality (Wieringa and Morali, 2012):

- The problem is framed,
- It is an example of a problem class,
- It has unambiguous goals.

Problems in the technical engineering sciences satisfy these assumptions and therefore, technical rationality can produce relevant solutions in a rigorous way (Schön, 1983, Hevner and Chatterjee, 2010).

The relevance of any design-science research effort is related to a constituent community. For information systems researchers, that constituent community is formed by the practitioners who plan, manage, design, implement, operate, and evaluate information systems and those who plan, manage, design, implement, operate, and evaluate the technologies that enable their development and implementation. To be relevant to this community, research must address the problems faced and the opportunities afforded by the interaction of people, organisations, and information technology. The environment defines the problem space in IS research, which includes people, organisations and technology. The research problem perceived by the researcher (derived from business needs) transpires from the environment. The business needs are influenced by people and are assessed and evaluated within the context of an organisation (organisational strategies, structure, culture, and existing business processes).

Accordingly, business needs are shaped in relation to the existing technology. Framing research activities to address business needs assures research relevance (Hevner et al., 2004). Design science research often begins by identifying and representing opportunities and problems in an actual application environment (Hevner and Chatterjee, 2010). The constituent community embraces artefacts that enable such problems to be addressed, constructs by which to think about them, models by which to represent and explore them, methods by which to analyse or optimise them, and instantiations that demonstrate how to affect them (Hevner et al., 2004).

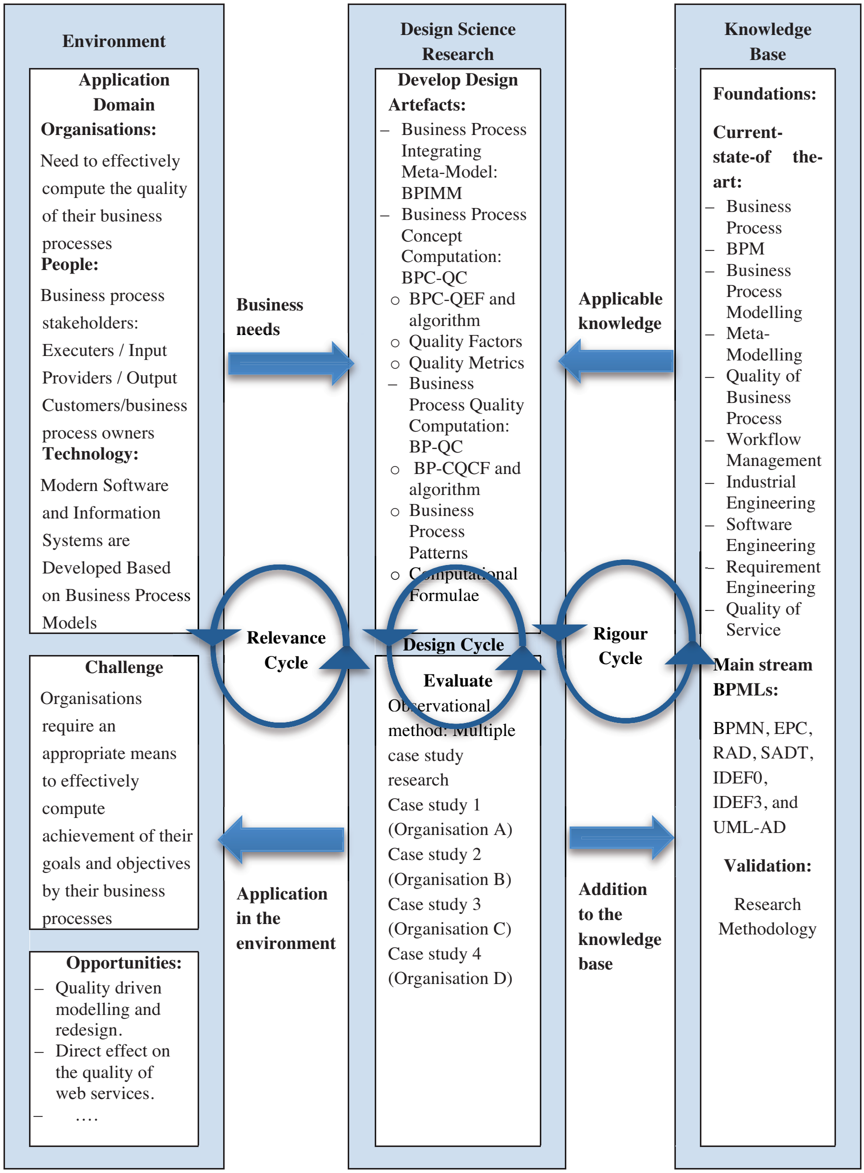

Figure 7 Design science research cycles

Rigour is achieved by appropriately applying existing foundations and methodologies. With respect to the construction activity, rigour must be assessed with respect to the applicability and generalisability of an artefact. In both design-science and behavioural-science research, rigour is derived from the effective use of the knowledge base-theoretical foundations and research methodologies (Hevner et al., 2004). The knowledge base provides the raw materials from and through which IS research is accomplished. The knowledge base provides foundations (theories, frameworks, instruments, constructs, models, methods, and instantiations) and methodologies (data analysis techniques, formalisms, measures, and validation criteria) that have resulted from prior research studies. The creation of artefacts in design science relies on existing core theories (referred to as foundations in this thesis) that are applied, tested, modified, and extended through the experience, creativity, intuition, and problem solving capabilities of the researcher (Markus et al., 2002). Methodologies provide the guidelines used in the justification/evaluation phase. Foundations are used during the design phase, while methodologies are used for evaluation during the behavioural science phase. The output from the design science research must be returned into the environment for study and evaluation in the application domain (Hevner and Chatterjee, 2010).

Having identified business requirements, IS research is conducted in two complementary phases - design science (develop/build) and behavioural science (justify/evaluate). During the design science phase, a researcher builds artefacts designed to meet business needs. The applicability of the designed artefacts to the business needs is then evaluated during the behavioural science phase (Hevner et al., 2004). Evaluation includes the integration of the artefact within the technical infrastructure of the business environment. As in the justification of a behavioural science theory, evaluation of a designed IT artefact requires the definition of appropriate metrics and possibly the gathering and analysis of appropriate data (Hevner et al., 2004).

A design artefact is complete and effective when it satisfies the requirements and constraints of the problem it is meant to solve (Hevner et al., 2004). The evaluation of the designed artefact typically uses methodologies available in the knowledge base. The "Case study" method is deployed in this thesis investigating a contemporary phenomenon within its real-life context (Yin, 2003) focusing on the integrations between information technology-related innovations and organisational context (Darke et al., 1998, Benbasat et al., 1987). In this thesis, a multiple case study is chosen as it allows cross-case analysis and comparison, and investigation of a particular phenomenon in diverse setting (Darke et al., 1998). Thus, several organisations are considered as the context of the case study. Three organisations are selected, which are able to ensure access to their people and resources.

They are referred to as Organisation A, Organisation B, and Organisation C[1]. Furthermore, there is a case from a Dutch research project called SlimVerbinden, referred to as Organisation D.

1.7. Structure of the Thesis

The structure of this thesis follows the Design Science Research Methodology (DSRM) discussed for design science discipline of information systems in (Peffers et al., 2007), seeking to address the following issues: (a) “What is the problem?”, (b) “How should the problem be solved?”, (c) “Create an artefact that solves the problem.”, (d) “Demonstrate the use of the artefact.”, and (e) “How well does the artefact work?”.

Based on these steps, the process model of DSRM is developed for this thesis, shown in Figure 8.

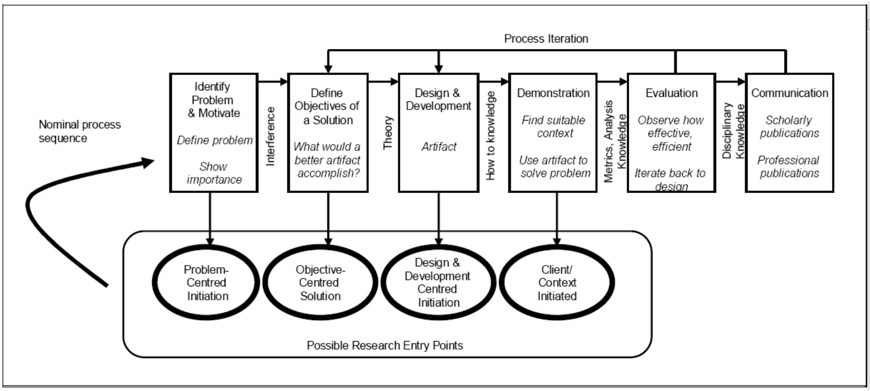

Figure 8 DSRM process model (adopted from (Peffers, Tuunanen et al. 2007))

This thesis describes the research in three main parts and seven chapters. The overall thesis structure is displayed in Figure 9. Issues (a) “What is the problem?” and (b) “How should the problem be solved?” are covered by Part I: Introduction (Chapters 1 and 2). Issue (c) “Create an artefact that solves the problem” is covered by “Part II: Proposition (Chapters 3, 4 and 5). Issues (d) “Demonstrate the use of the artefact” and (e) “How well does the

[1] For confidentiality reasons, the organisations’ names cannot be revealed.

artefact work in terms of efficiency and utility?" are covered by "Part III: Application and Validation" (Chapters 6,7,8,9,10, and 11). Following this introductory chapter covering research objectives, research questions and research method, the succeeding chapters are organised as follows.

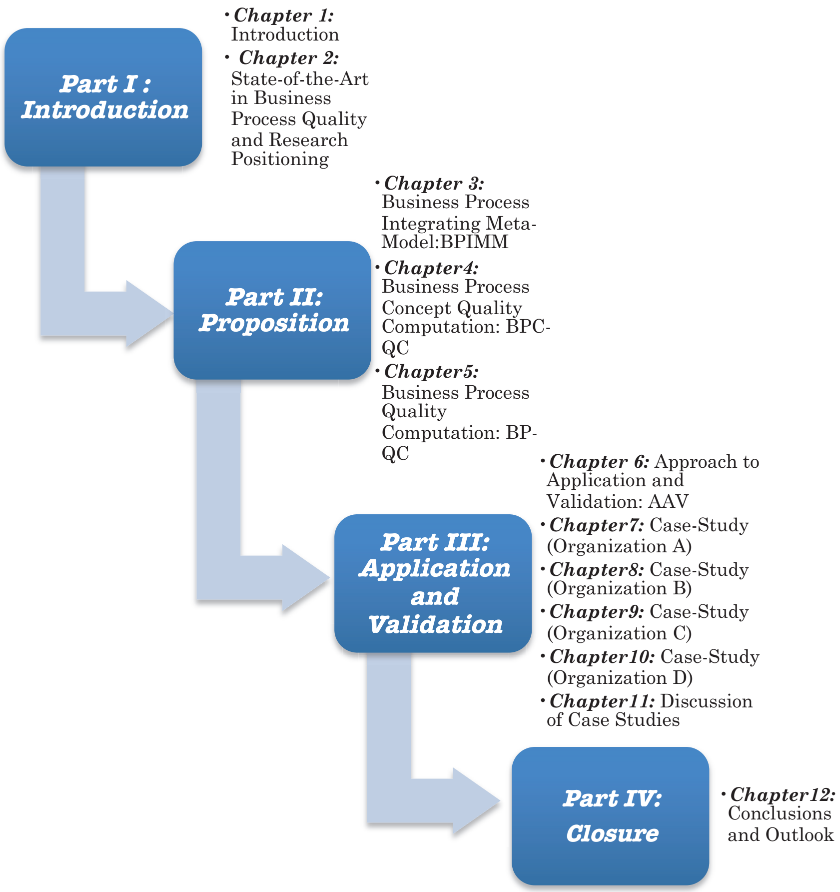

Figure 9 Thesis structure

Chapter 2 presents an analysis of the-state-of-the-art with respect to quality in business processes, extending the literature review in (Heidari and Loucopoulos, 2013), (Heidari et al., 2013b), (Heidari et al., 2013a), (Heidari et al., 2011), and (Loucopoulos and Heidari, 2012).

Chapter 3 describes a business process integrating meta-model (BPIMM) that integrates the semantics of seven mainstream business process modelling languages. An ontological analysis of the business process meta-model is also conducted based on BWW ontology (Wand and Weber, 1993), extending (Heidari et al., 2013c), (Heidari et al., 2013b), and (Heidari et al., 2011).

Chapter 4 presents BPC-QC encompassing a set of quality dimensions, factors and metrics for the key concepts of business processes. The quality factors are categorised into different dimensions reflecting different aspects of the quality a business process concept, namely: performance, efficiency, reliability, recoverability, permissibility and availability. A Business Process Concept Quality Evaluation Framework and an algorithm are developed to provide a generic way of working to quantitatively evaluate the quality of a business process concept, extending (Heidari and Loucopoulos, 2013).

Chapter 5 describes BP-QC: (a) BP-CQCF and algorithm as methods steps for conducting compositional quality computation, (b) generic patterns of business process models that are defined on the basis of the relations between the concepts of the business process integrating meta-model, and (c) computational formulae that enable computing the quality of a (part of) business process, based on the results of the computation of its constituent concepts. For each quality factor introduced in Chapter 4 and each business process pattern, a computational formula is introduced. The thesis contributions are published in a few papers (see (Heidari et al., 2013b) and (Heidari et al., 2013a)).

Chapter 6 discusses the Approach to Application and Validation (AAV). In doing so, the case study plan is discussed and justified.

Chapter 7 describes a case study embedded in Organisation A. The case study focuses on a management accounting business process, called “dealing Invoices”, which is used to illustrate and evaluate the workings of the proposed approach.

Chapter 8 describes a case study embedded in Organisation B. The case study focuses on a business process, of which the name cannot be revealed.

Chapter 9 describes a case study embedded in Organisation C. The case study focuses on a business process called “accepting client”.

Chapter 1 describes a case study embedded in Organisation D. The case study focuses on a crisis management scenario used in the project.

Chapter 11 provides a discussion of the findings of the four case studies.

Chapter 12 discusses and concludes the thesis. Strengths and weaknesses are discussed. The initial goals and objectives are evaluated. Contributions to the research and practice and possible areas for future research are proposed.

Figure 10 illustrates the chapters in relationship to the research design provided in section 1.6.3 and Figure 7.

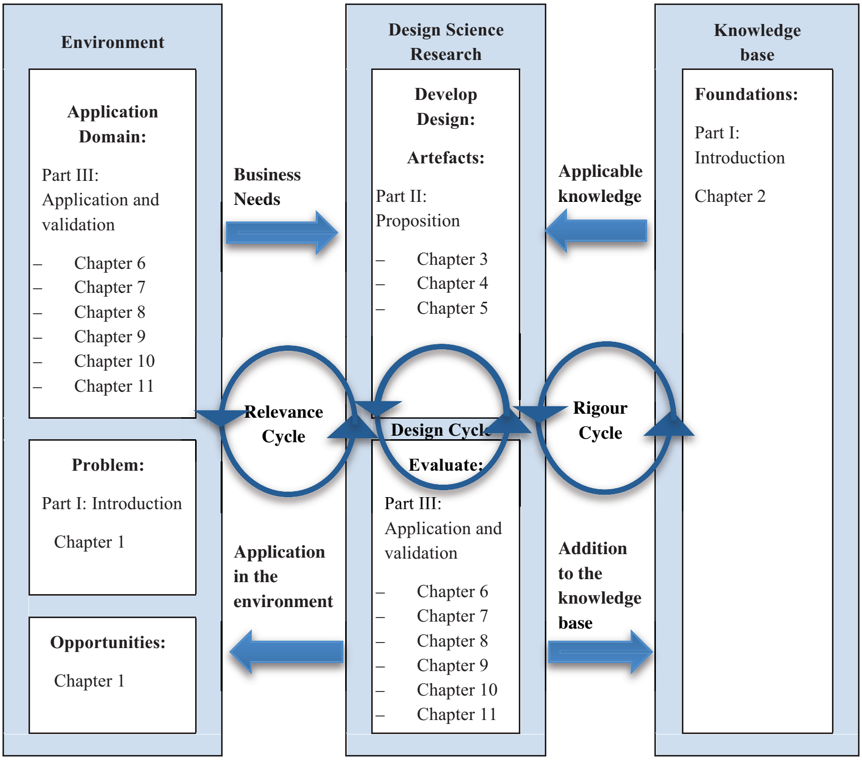

Figure 10 Thesis structure in relation to the research design

1.8. Chapter Summary

This chapter elaborates on the motivation of the research. With regards to the research assumptions, research questions are described and corresponding research deliverables are provided. Considering the philosophical position of the researcher, a research design is provided. Following DSRM, a structure is presented for the research, providing a structured way for presentation of the research in different steps, from identification of the problem to evaluation of the research.

Chapter 2. The State-of-the-Art in Business Process Quality and Research Positioning

2

If I have seen further
it is by standing on the shoulders of giants.
-Isaac Newton

2.1. Introduction

Today, new business forces are demanding enterprises to understand the behaviour of their business systems. Rapid organisational change, knowledge-intensity of goods and services, the growth in organisational scope, and information technology has intensified organisational needs for techniques providing them such understanding (Loucopoulos and Heidari, 2012). To this end, business process modelling has become an important part of work practices, culminating in standards such as the Business Process Modelling Notation (BPMN) (OMG, 2009), but also in fruitful research endeavours involving the evolution from information modelling to enterprise modelling (Loucopoulos, 2000b), and in schemes for the modelling of business goals (Yu and Mylopoulos, 1998, Kavakli and Loucopoulos, 2006), business objects (Sutherland, 1995), and business rules (Loucopoulos and Katsouli, 1992b).

There is a commonly agreed set of features pertaining to business processes (Alderman et al., 1997, Davenport, 1993, Ould, 1995, Broadbent, 1999, Scheer and Nuttgens, 1994, Yu and Mylopoulos, 1996):

- A business process has well-identified products and customers.
- A business process has goals, that is, it is intended to achieve defined business objectives aiming to create value to customers.
- A business process involves several activities, which collectively realise the business process's goals.
- A business process crosses functional and/or organisational boundaries; it concerns the collaboration between organisational actors that are contributing to (or constraining) the achievement of business objectives.

Note the following two aspects:

First, business processes involve many different stakeholders. Any change to business processes involves stakeholders to consider the effect that new designs have on work practices, on the added value offered by the new processes, on the cost involved in running the business with the new processes and more generally on how well the new processes meet their quality requirements (Loucopoulos, 2003). Approaches used to address stakeholder collaboration include collaborative requirements management (Lang, 2001), scenarios (Kavakli et al., 1996), visualisation (Lalioti and Loucopoulos, 1993), use of domain knowledge (Rolland et al., 1998), use of indicators (Horkoff et al., 2012), and model transformation (Loucopoulos, 1995).

Second, business processes exhibit complex dynamic behaviour. This complexity is not so much the result of voluminous components (although this could indeed be the cause in some cases). More often, it is the large number of interrelationships and dependencies between system components that may involve a great deal of diversity from operational to strategic, legislative and financial factors. Even in systems with a relatively small number of parts, changes that involve the simultaneous modification of many variables (some of which may be distant in space and time) can be difficult or impossible to understand without appropriate support mechanisms. Having an understanding of this rate of change allows one to make predictions about alternative implementations. Approaches to address the problem of causality in complex dynamic businesses include systems thinking (Sterman, 2000), modelling of system behaviours (Tsalgatidou and Loucopoulos, 1990), architecture-driven prioritisation (Koziolek, 2012), and simulation (Loucopoulos et al., 2003c).

The focus of this thesis is on quality of business processes. A variety of standards and frameworks are introduced in the literature to define, manage, assure, control, and improve the quality of processes (Heravizadeh et al., 2008). The plethora of approaches has led many authors to reflect on the value of comparing and evaluating such approaches. Different evaluation techniques are proposed for the development of frameworks (Falckenberg et al., 1998), the use of structuralism (Pfeiffer and Niehaves, 2005), the exploitation of paradigmatic discussion (Recker, 2005), the use of ontological, qualitative and quantitative analysis (Recker, 2011), and systematic classification (Loucopoulos et al., 2013). The main contribution of this chapter is to position the thesis within the current state-of the-art on modelling, evaluation, reengineering or simulation approaches to quality of business processes.

Following the concept-centric approach by (Webster and Watson, 2002), the thesis introduces key concepts to determine the organising framework of the review. For each approach, key concepts are realised and compiled in a concept matrix, and grouped together. The most prominent concepts are selected which mostly highlight variations in quality of measurement and specification. For each concept, relevant units of behaviour demonstrate the different aspects of a concept (e.g., quantitative vs. qualitative in the measuring concept). Together, the key concepts and units of behaviour form a framework to analysis papers in the area of business process quality.

This chapter bases the analysis and comparison of papers on five orthogonal concepts and corresponding units of behaviour. The conducted analysis is subjective in nature. Each concept describes a characteristic that, in turn, can be classified in one of two ways as a unit of behaviour. These concepts are the building blocks of an organising framework for literature review comparative analysis (Figure 11). Each concept describes a characteristic that, in turn, can be classified in one of two ways as a unit of behaviour.

The concepts and their corresponding units of behaviour are defined as follows:

1. **Concept**: granularity level**; Units of behaviour**: high vs. low:

   The granularity concept is concerned with the focus on different abstraction levels. Different levels of granularity can be considered to realise and compute quality of a business process. The business process as a whole or a sub-process is considered to be a high-level granularity, and an individual concept of a business process is a low-level granularity. This classification is subjective.

2. **Concept**: modelling; **Units of behaviour:** use of formal language (yes/no) and language dependency (yes/no) [1]:

   The modelling concept is concerned representation a business process and associated quality factors as the basis for assessment. There are two considerations: Does the paper use a formal or semi-formal ‘language’ or is it mostly based on textual descriptions and narrative (informal)? And if the paper uses a descriptive language, is this representation tied to a particular BPML or is it independent?

3. **Concept:** methodology; **Units of behaviour:** systematic and ad hoc:

   The methodology concept is concerned with the way an approach may be practiced. If a set of phases is prescribed with details on the ‘way of working’ within each phase, that is: (a) focus of work, (b) required inputs, (c) expected outputs, (d) techniques used, and possibly (e) support tools, the paper is considered to be systematic and otherwise ad-hoc. An ad-hoc paper only provides general principles and guidelines and can be used in an improvised manner.

4. **Concept:** measuring; **Units of behaviour:** quantitative vs. qualitative:

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[1] Note that “use of formal language” and “language dependency” are not entirely orthogonal, hence they together form one concept rather than two separate concepts.

2

The measuring concept is concerned with the degree to which an a paper supports quantitative measures, meaning that the results of an evaluation are based quantitative values, or that a paper supports qualitative measures, meaning that the results are based on analysis requiring individual judgment and interpretation.

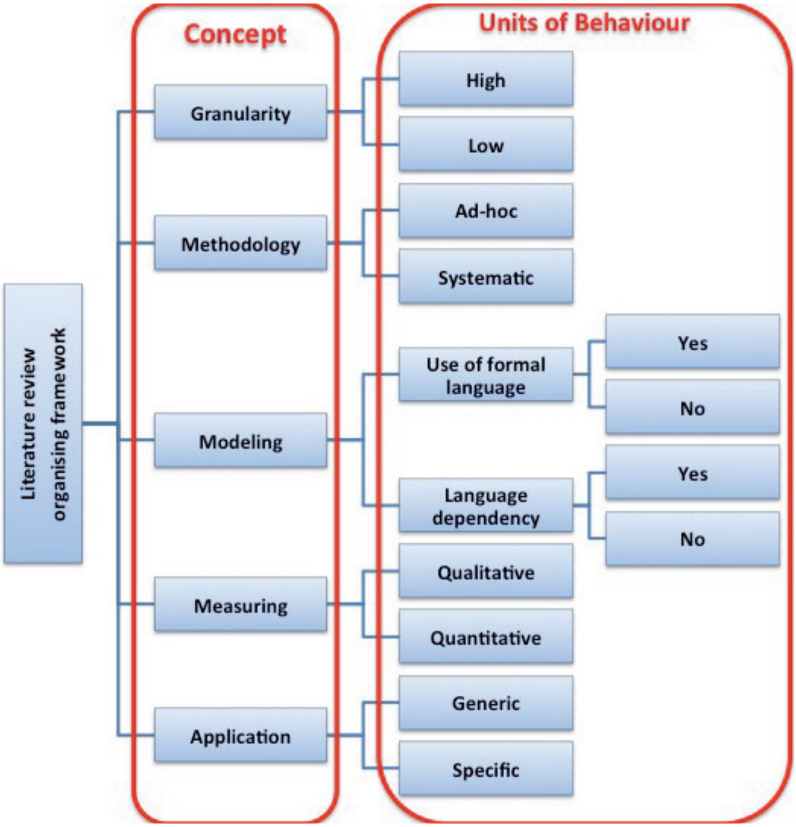

Figure 11 Concepts and units of behaviour of the organising framework

5. **Concept:** application; **Units of behaviour:** specific and generic:

The application concept is concerned with the targeted applications of the paper for measurement and specification. Each paper is evaluated according to whether it is generic (i.e., the results can be applied to all or most situations), or specific, (i.e., the paper is dedicated to a particular class of applications or business sector).

A high-quality review is complete, that is, it covers relevant literature on the topic and focuses on concepts (Webster and Watson, 2002). To this end, the areas of business and management, requirement engineering, software engineering, workflow analysis, industrial engineering, system dynamics, business process reengineering, and discrete-event simulation are searched. Search strings are business process, performance, quality, service, business process modelling, measurement, evaluation, computation, estimation, requirements, non-functional requirements, simulation, optimisation, and quality control as well as different quality aspects such as security, reliability, etc. and if appropriate combined by Boolean AND's and OR's. Journal papers, conference proceeding, books and book chapters from 1993 or later (i.e., the past 20 years) are selected for review if they have a key term (or synonym) in the title, abstract or keywords list. Electronic databases such as IEEE Xplore, Science direct, Wiley, Elsevier, JSTOR, Emerald, Springer, and Google Scholar are searched to find the relevant papers.

After applying the inclusion/exclusion criterion, namely its contribution to modelling and/or evaluating and/or simulating quality requirements, sixty four papers remained, of which forty four (69%) are conducted in the last ten years. The following subsections synoptically investigate the selected sixty four papers against the aforementioned five concepts. On the basis of the analysis, the current state-of-the-art is synthesised, the areas of research that deserve more attention are highlighted, and the current research is positioned.

This chapter is organised as follows. Sections 2.2 provides a dialectic discussion of the papers in fulfilling different concepts and units of behaviour. Section 2.3 presents an analysis in the form of a classification matrix and a statistical analysis of the findings against different concepts and units of behaviour. On the basis of this analysis, Section 2.4 discusses a number of observations and reflections and positions the thesis, given the organising concepts. Section 2.5 provides a summary of the chapter.

2.2. Current state-of-the-art

This section discusses different papers to modelling, evaluating or simulating quality with regards to five concepts of analysis: (1) granularity, (2) modelling, (3) methodology, (4) measuring, and (5) application.

2.2.1. Granularity

Quality can be computed at different levels, namely business, business unit and business process (Evans and Lindsay, 2004) and individual business process concepts (Heidari and Loucopoulos, 2013). Business performance measurement systems identify performance factors at the organisational level or organisational unit level (Evans and Lindsay, 2004, Kaplan and Norton, 1993). Existing research on business performance measurement systems (Kueng, 2000, Heckl and Moormann, 2010) focuses on providing guidelines for developing such systems without introducing quality factors and metrics. In TQM (Total

Quality Management), the cooperation of all employees within an organisation and associated business processes is encouraged to produce value-for-money products and services which meet, and hopefully exceed, the needs and expectations of customers (Dale et al., 2007). The ISO 9000 series of standards (ISO, 2000) focuses on quality management systems. Quality approaches in business and management, such as ISO standards and TQM have the focus on the organisational level of an enterprise.

Evaluating quality at different levels of granularity of a business process can also involve measuring the quality of at the business process level (Cardoso et al., 2004, Heidari et al., 2013b, Zo et al., 2010, Canfora et al., 2008, Jaeger et al., 2004, Zheng et al., 2010, Cao et al., 2013, Pourshahid et al., 2008, Reijers, 2003) (Oliveira et al., 2012, Chuang et al., 2002) or individual elements in a business process (Heidari and Loucopoulos, 2013, Heinrich and Paech, 2010, Heravizadeh, 2009). (Heidari and Loucopoulos, 2013) offers formulae for measuring quality of business process concepts, namely, activity, event, input and output. Concepts of activity, resource, actor, information and physical resource are considered in the research by (Heinrich and Paech, 2010). With regards to the four essential process competencies in operations management, namely: (a) process cost, (b) process flow time, (c) process flexibility and (d) process quality, (Heravizadeh et al., 2008) identifies four generic quality categories for business process quality. These categories are: “function”, “input-output”, “non-human resource” and “human resource”. Based on related work from software engineering, they identify sixteen quality dimensions for functions, product quality and quality-of-service for web services, quality dimensions for non-human resources, and quality dimensions for input-output and human resources.

2.2.2. Modelling

Modelling is concerned with the representation a business process. To this end, formal or semi-formal languages are used in a representation (e.g., (Heravizadeh et al., 2008, Decreus and Poels, 2010, Aburub et al., 2007)). Language dependency indicates if an approach’s focus is on a specific language. Language-independent approaches are not tied to any specific modelling languages (e.g., (Si-Said-Cherfi et al., 2013, Kedad and Loucopoulos, 2011, Heidari and Loucopoulos, 2013, Heidari et al., 2013b, Heidari et al., 2011)).

(Heinrich et al., 2011) uses the quality characteristics and attributes of processes for modelling quality information within business process models. They rely on the ISO/IEC standard for software quality (ISO/IEC, 2004) to enhance BPMN. (Saeedi et al., 2010) proposes a set of quality requirement factors for BPMN concepts. Role Activity Diagram notation is considered for representation of business processes by (Aburub et al., 2007). The strategic rationale for the choice of business processes to be specified in BPMN models is considered by (Decreus and Poels, 2010). Workflow expressions of services are the focus of the work by (Cardoso et al., 2004). (Glykas, 2011) proposes an approach to model and analyse a process, and enact it for simulation purposes.

Considering contexts of business process models, (Pavlovski and Zou, 2008) introduces new artefacts to model the constraints associated with a business process: completion time, security privilege, availability of a business process, and regularity or organisation constraints. (Wolter et al., 2009) presents an approach expressing security goals in the context of a business process model. The foundation of the work constitutes a generic security model specifying security goals, policies, and constraints. Having a language independent approach, (Heidari and Loucopoulos, 2013) identify quality metrics and factors for business process concepts having its model as given.

Petri nets is a widely used notation for performance evaluation as well as incorporation of quality concepts such as time (Coves et al., 1998, Chuang et al., 2002, Tsironis et al., 2010, Van Der Aalst et al., 2000b, van der Aalst and van Dongen, 2002). On the basis of Petri nets, (Reijers, 2003) proposes a model called stochastic workflow net (SWN) enabling numerially computation of distribution of workflow execution time. A generalised stochastic Petri net approach is proposed by (Oliveira et al., 2012) for performance evaluation purposes.

Business process meta-model is introduced as element in a framework for evaluation of business process quality in (Kedad and Loucopoulos, 2011). (Heidari et al., 2011) introduces a business process meta-model as an integration of concepts of seven business process modelling techniques. The meta-model is enriched with quality related information (i.e. quality factors). The result is presented as a quality-oriented meta-model encompassing quality factors of throughput, cycle time, timeliness, cost, resource efficiency, cost efficiency, maturity, recoverability, security and availability. Use of domain knowledge for improving the semantic quality of business process models with the aid of meta-modelling is considered in the work by (Si-Said-Cherfi et al., 2013).

2.2.3. Methodology

When an paper prescribes “focus of work”, “required inputs”, “expected outputs” and a “set of phases” in detail, the paper is considered to be systematic in terms of methodology (e.g., (Decreus and Poels, 2010, Donzelli and Bresciani, 2004, Glykas, 2011, Heidari and Loucopoulos, 2013, Heidari et al., 2013b, Cao et al., 2013)); otherwise the paper is considered to be ad-hoc (e.g., (Lohrmann and Reichert, 2013a, Firesmith, 2005)). Approaches such as TQM and ISO standards propose general guidelines and recommendations for quality on an organisational level.

(Wolter et al., 2009) deploys a method to assign elements of their security model to a process model. Capturing quality dimensions of a business process by way of a framework is considered by (Heravizadeh et al., 2008). A framework for evaluation of business process quality is introduced by (Kedad and Loucopoulos, 2011). This framework includes a business process meta-model, a quality-based business process meta-model, enrichment of business process meta-models, selection/execution of quality services, quality requirements, definition of quality factors and metrics, and definition of quality evaluation services and quality repository as its elements.

A set of formal models of business design problems is introduced by (Hofacker and Vetschera, 2001). It can be used to analytically determine optimal design with respect to various objective functions such as cost, time and, quality of service. Using AHP (Analytic Hierarchy Process), a decision strategy is developed by (Limam Mansar et al., 2009) for improving the efficiency of business process reengineering and to conduct a more systematic evaluation of improvement opportunities.

A requirements engineering framework with the aim of allowing active stakeholder participation is introduced by (Donzelli and Bresciani, 2004). The framework focuses on soft goals as well as hard goals in organisational modelling. By providing an abstraction to encourage participation of stakeholders, the focus is on subjectively examining the impact of requirements on business processes and organisational model beforehand rather than during the execution of business processes. (Pourshahid et al., 2008) introduces a framework to subjectively measure and align processes and goals. In their work, key performance indicators (KPIs) are added to user requirement notation (URN), together with explicit goals for each business process. A scenario-based methodology and a toolset for business process modelling and analysis are introduced by (Glykas, 2011). The paper defines and measures KPIs in a qualitative manner as well as a quantitative manner. The toolset is able to define different scenarios, assess the performance, and report the deviation from the desired situation.

(Aburub et al., 2007) introduces a structured method for modelling specific QRs. (Heidari and Loucopoulos, 2013) proposes a framework in the form of meta-models to capture and evaluate quality of individual concepts of business processes, considering non-functional requirements defined by stakeholders. The evaluation results are compared with the quality objectives. (Firesmith, 2005) utilises a checklist identifying defects in software-intensive system architectures. Measurement is included, although the process toward the measurement is not discussed. (Lohrmann and Reichert, 2013a) provides a definition for business process quality and introduces a business process quality model; however, there are no details on how the measurement should be conducted.

2.2.4. Measuring

The measuring aspect is concerned with the degree to which a paper can support quantitative measures, that is, the results of an evaluation based on quantitative metrics (e.g., (Cardoso et al., 2004) and (Heidari and Loucopoulos, 2013)), or qualitative measures, that is, the results based on analysis requiring individual judgement and interpretation (e.g., (Adam et al., 2009)).

(Reijers, 2003) categorises quantitative techniques into simulation and analytical techniques. During a simulation of a workflow at specified intervals, cases (e.g., new orders) are generated for the model in execution. In response, each of the components within the model will behave in accordance with its pre-defined specification (Reijers, 2003). System dynamics and discrete-event simulation are two kinds of simulation deployed for quantitative evaluation. (Powell et al., 2001) and (An and Jeng, 2005) implement a System Dynamics approach to measure and control business processes. Their analysis focuses on performance measures, such as "shipping rate" and "product inventory". Discrete-event simulation is used for simulating and analysing business processes in (Nidumolua et al., 1998). This approach of simulation is used specifically for business process re-engineering processes (Hlupic and Robinson, 1998) and for the introduction of new information technologies (East et al., 2009).

An analytical technique is based on an algorithm that yields an exact result on the basis of both the formal model and some well-understood relationships between the specified components (Reijers, 2003). Popular formalisms and mathematical theories to model and analyse business processes mentioned by (Reijers, 2003) are, for example, Petri nets (Coves et al., 1998, Chuang et al., 2002, Tsironis et al., 2010, Van Der Aalst et al., 2000b), Markov chains (Li et al., 2004), queuing networks theory (van der Aalst and Van Hee, 2002), GERT (Neuman and Steinhardt, 1979), and CPM and PERT (Levin and Kirkpatrick, 1966).

The majority of papers concerning Petri nets focuses on time computation or incorporation of time into the business process model. (Tsironis et al., 2010) introduces a method for estimating cycle time of stochastic Petri nets by means of model analysis and block reduction. (Chuang et al., 2002) introduces a method for cycle time analysis of workflow systems based on stochastic Petri net models. (Van Der Aalst et al., 2000b) extends the mining techniques to incorporate time and other attributes such as queue time (van der Aalst and van Dongen, 2002). The approach is based on Petri nets and timing attached to places. (Reijers, 2003) proposes a Petri net-based model, called stochastic workflow net (SWN), which is able to compute numerically the distribution of workflow execution time. (Oliveira et al., 2012) proposes a generalised stochastic Petri net approach for performance evaluation of business processes.

In the quantitative approach, identifications of metrics and procedures for measuring a business process are core concerns. Most quantitative research to measure performance is in the area of industrial engineering, where measurement does not consider the context of business process modelling (Anupindi et al., 1999). These approaches develop and recommend ways for managing process flows by defining product attributes as those properties considered important by customers, such as cost, product delivery response time, product variety and product quality. Quality metrics, such as flow time, inventory turns or turnover ratio, throughput, capacity utilisation, net availability of a resource, capacity utilisation, and inventory holding costs are introduced in this work. (Heidari and Loucopoulos, 2013) identifies quality dimensions of performance, efficiency, reliability, recoverability, permissibility and availability for corresponding business process concepts and introduce quantitative formulae for evaluating them.

The quality computation of a business process on the basis of its constituent activities' quality values is addressed in the area of workflows and services, prediction of some quality factors (i.e. time, cost, fidelity and reliability) by (Cardoso et al., 2004). Specifically, results of measuring constituent activities of a business process are incorporated in the measurement of the business process (e.g., (Zo et al., 2010, Canfora et al., 2008, Zheng et al., 2010, Jaeger et al., 2004) in the area of workflow and web-services). (Cardoso et al., 2004) estimates of workflow properties (e.g., execution cost, execution time, and reliability), using the properties of activities constituting block-structured process models containing sequences, XOR blocks, AND blocks, and structured loops. Reduction of patterns is the common technique of analytical models in quantitative approaches. (Polyvyanyy et al., 2009) introduces an approach for abstracting business process models to reduce the complexity considering the concept of "parent and child". (Polyvyanyy et al., 2008) introduces an approach for reducing complexity of large EPCs (event-driven process chains) using a set of elementary abstractions (i.e. patterns). (Chuang et al., 2002) considers sequential, parallel, exclusive, and loop as four basic routing patterns of workflow systems and provides formulae for cycle time estimation. (Sadiq and Orlowska, 2000) applies a set of reduction rules to predefined patterns identifying structural conflicts in process models. (Vanhatalo et al., 2009) describes an approach for the decomposition of a workflow graph into a hierarchy of sub-workflows and the labelling of each category with a syntactic category to which they belong, such as sequence, if, repeat-until, etc. (Cao et al., 2013) transforms a service process model into a process structure tree for quality calculation using four control nodes: ANDSplit, ANDJoin, XORSplit, and XORJoin. (Cardoso et al., 2004) deploys a Stochastic Workflow Reduction (SWR) algorithm replacing identified patterns with a single task to estimate workflow properties.

In the context of business process redesign, the quality and performance of a new business process is a concern. There are several heuristic rules for redesigning business processes that can be evaluated along the measures of cost, flexiblity, time, and quality of service (Reijers and Liman Mansar, 2005). Using a measurement driven inference, (Nissen, 1998) conducts redesigning and reengineering of business processes. (Hofacker and Vetschera, 2001) provides an analytical support for optimising the design of business processes considering cost, time, and quality of service. Considering the criteria of popularity, impact (i.e., quality, time, cost, and flexibility), goal, and risk, a strategy for implementation of business process redesign is introduced using AHP (Analytic Hierarchy Process) (Limam Mansar et al., 2009).

Most managerial approaches (e.g., TQM (Dale et al., 2007), ISO standards (ISO, 2000), literature on business performance measurement (Kueng, 2000), quality tools and techniques (Eriksson and Penker, 2000) provides generic guidelines and assistance for organisations, while the realisation of the quality factors and metrics are not in their scope.

(Adam et al., 2009) focuses on software systems and adequacy of business processes in supporting these systems. Their work focuses on the understanding of quality issues based on goal analysis, and heavily relies on interviews. The work by (Firesmith, 2005) proposes a checklist of questions to identify defects in software-intensive system architectures.

2.2.5. Application

The application scope aspect is concerned with the target area of the paper. Generic approaches can be applied to all or most situations (e.g., (Loucopoulos and Heidari, 2012, Kedad and Loucopoulos, 2011, Heidari and Loucopoulos, 2013)). Specific approaches (e.g., (Wolter et al., 2009, Aburub et al., 2007)) are dedicated to a particular class or application or business sector. From a managerial point of view, TQM and ISO quality standards act as general guidelines that are applicable to all types of organisation regardless of the types of product and service they offer, organisation size, turnover, etc. The literature on business process performance measurements systems provides generic guidelines for developing business process performance measurement systems (e.g., (Kueng, 2000) and (Heckl and Moormann, 2010)). Quality tools and techniques (Dale et al., 2007) and tools for process improvement, such as Kaizen Blitz, Poka-Yoke and process simulation (Eriksson and Penker, 2000) are generic and designed to assist stakeholders in improving their processes and presenting output of quality measurements without realising quality dimensions, factors and metrics.

(Wolter et al., 2009) focuses on security requirements. (Aburub et al., 2007) introduces an approach to remodelling business processes for identification and inclusion of QRs for a specific case. With the focus on the quality of a business process model, the work by (Si-Said-Cherfi et al., 2013) considers ontologies in a number of specific domains. (Powell et al., 2001) and (An and Jeng, 2005) focus on the area of supply chain management and define quality dimensions, factors and metrics for a specific situation. Similar to the efforts in system dynamics, discrete-event simulation is used for simulation and analysis purposes. These papers define quality dimensions and factors for specific situations (East et al., 2009, Nidumolua et al., 1998, Hlupic and Robinson, 1998).

2.3. Analysis

This section presents an analysis of the current state-of-the-art using the concepts distinguished and discussed above namely: granularity, methodology, modelling, measuring, and application. Table 1 presents the established knowledge and limitations that exist in the state-of-the-art. Furthermore, to make sense of the accumulated knowledge, for each concept a statistical analysis of different units of behaviour is performed to indicate the current state-of-the-art and reveal gaps in research literature.

Table 1 Summary of the current state-of-the-art against the five concepts and units of behaviour

Paper	Concepts and units of behaviour											
	Granularity		Methodology		Modelling				Measuring		Application	
	High	Low	Ad-hoc	Sys.	Use of formal language		Language dependency		Qual.	Quant.	Spec.	Gen.
					Yes	No	Yes	No				
(Dale et al., 2007)	✓		✓			✓	NA	NA	NA	NA		✓
(ISO, 2005)	✓		✓			✓	NA	NA	NA	NA		✓
(Evans and Lindsay, 2004)	✓		✓			✓	NA	NA	NA	NA		✓
(Kaplan and Norton, 1993)	✓		✓			✓	NA	NA	NA	NA		✓
(Heckl and Moormann, 2010)	✓		✓			✓	NA	NA	NA	NA		✓
(Kueng, 2000)	✓		✓			✓	NA	NA	NA	NA		✓
(Eriksson and Penker, 2000)	✓		✓			✓	NA	NA	NA	NA		✓
(Adam et al., 2009)	✓			✓	✓			✓	✓			✓
(Bachmann et al., 2003)	✓			✓	✓			✓	NA	NA		✓
(Boehm, 1996)	✓			✓	✓			✓	NA	NA		✓
(Donzelli and Bresciani, 2004)	✓			✓	✓			✓	NA	NA		✓
(Glinz, 2000)	✓			✓	✓			✓	NA	NA		✓
(Loucopoulos and Garfield, 2009)	✓			✓	✓			✓	NA	NA		✓
(Anupindi et al., 1999)		✓	✓			✓	NA	NA		✓		✓
(Powell et al., 2001)		✓	✓		✓		✓			✓	✓	
(An and Jeng, 2005)		✓	✓		✓		✓			✓	✓	

Paper	Concepts and units of behaviour											
	Granularity		Methodology		Modelling				Measuring		Application	
	High	Low	Ad-hoc	Sys.	Use of formal language		Language dependency		Qual.	Quant.	Spec.	Gen.
					Yes	No	Yes	No				
(Nidumolua et al., 1998)	✓	✓	✓		✓		✓			✓	✓	
(Hlupic and Robinson, 1998)	✓		✓		✓		✓			✓	✓	
(East et al., 2009)		✓	✓		✓		✓			✓	✓	
(Heravizadeh et al., 2008)		✓		✓	✓		✓		✓			✓
(Heinrich and Paech, 2010)		✓	✓		✓		✓		NA	NA		✓
(Heinrich et al., 2011)		✓	✓		✓		✓			✓		✓
(Kedad and Loucopoulos, 2011)	✓	✓	✓		✓			✓	NA	NA		✓
(Pavlovski and Zou, 2008)	✓	✓	✓		✓		✓		NA	NA		✓
(Wolter et al., 2009)		✓	✓		✓			✓	NA	NA	✓	
(Pourshahid et al., 2008)	✓		✓			✓	NA	NA	NA	NA		✓
(Saeedi et al., 2010)	✓	✓	✓		✓		✓			✓		✓
(Decreus and Poels, 2010)		✓		✓	✓		✓		NA	NA		✓
(Firesmith, 2005)	✓			✓		✓	NA	NA	✓			✓
(Aburub et al., 2007)	✓		✓		✓		✓		NA	NA		✓
(Si-Said-Cherfi et al., 2013)	✓	✓	✓		✓			✓	NA	NA	✓	
(Glykas, 2011)	✓	✓	✓		✓			✓	✓	✓	✓	
(Lohrmann and Reichert, 2013b)	✓		✓		✓			✓	NA	NA		✓
(Heidari and Loucopoulos, 2013)		✓	✓		✓			✓		✓		✓
(Cardoso et al., 2004)	✓			✓	✓			✓		✓		✓
(Zo et al., 2010)	✓			✓	✓		✓			✓		✓
(Canfora et al., 2008)	✓		✓		✓		✓			✓		✓
(Heidari et al.,	✓	✓	✓		✓			✓	NA	NA		✓

Paper	Concepts and units of behaviour											
	Granularity		Methodology		Modelling				Measuring		Application	
	High	Low	Ad-hoc	Sys.	Use of formal language		Language dependency		Qual.	Quant.	Spec.	Gen.
					Yes	No	Yes	No				
2013b)												
(Loucopoulos and Heidari, 2012)		✓	✓		✓			✓	NA	NA		✓
(Heidari et al., 2011)		✓	✓		✓			✓	NA	NA		✓
(Jaeger et al., 2004)	✓			✓	✓			✓		✓		✓
(Zheng et al., 2010)	✓		✓		✓			✓		✓		✓
(Cao et al., 2013)	✓		✓		✓			✓		✓		✓
(Polyvyanyy et al., 2008)	✓		✓		✓			✓	NA	NA		✓
(Sadiq and Orlowska, 2000)	✓		✓		✓		✓		NA	NA		✓
(Vanhatalo et al., 2009)	✓		✓		✓		✓		NA	NA		✓
(Vanderfeesten et al., 2007)	✓			✓	✓			✓		✓		✓
(Guceglioglu and Demirors, 2005)	✓		✓		✓			✓		✓		✓
(Cardoso et al., 2002b)	✓	✓		✓	✓		✓			✓		✓
(Dikici et al., 2012)	✓			✓	✓		✓		✓			✓
(Lohrmann and Reichert, 2010)	✓		✓			✓	NA	NA	NA	NA		✓
(Heidari et al., 2013a)		✓		✓	✓			✓		✓		✓
(Bocciarelli and D'Ambrogio, 2011)		✓		✓	✓		✓		NA	NA		✓
(Tsironis et al., 2010)	✓			✓	✓		✓			✓		✓
(Chuang et al., 2002)	✓			✓	✓		✓			✓		✓
(van der Aalst and van Dongen, 2002)	✓			✓	✓		✓			✓		✓
(Van Der Aalst et al., 2000b)	✓			✓	✓		✓			✓		✓
(Reijers, 2003)	✓			✓	✓		✓			✓		✓
(Oliveira et al., 2012)	✓			✓	✓		✓			✓		✓

Paper	Concepts and units of behaviour											
	Granularity		Methodology		Modelling				Measuring		Application	
	High	Low	Ad-hoc	Sys.	Use of formal language		Language dependency		Qual.	Quant.	Spec.	Gen.
					Yes	No	Yes	No				
(Reijers and Liman Mansar, 2005)	✓			✓	✓			✓	✓			✓
(Hofacker and Vetschera, 2001)	✓			✓	✓		✓			✓		✓
(Coves et al., 1998)	✓				✓		✓		NA	NA		✓
(Nissen, 1998)	✓			✓	✓			✓		✓		✓
(Limam Mansar et al., 2009)	✓			✓		✓		✓	✓			✓

NA = Not Applicable

Figure 12 shows six pie-chart graphs, each of which compares the relative coverage in the literature of different units of behaviour for a key concept. The relative coverage of a specific unit of behaviour is determined as the percentage of the sixty four investigated papers deploying that specific unit of behaviour. This analysis provides an understanding of the areas that are dominant in the literature, or that receive less attention. This leads to a recognition of the gaps in literature and directions for future research. The analysis reveals the following for each concept:

1. Granularity: The high levels of granularity are the focus of more than half of the papers (66%), whereas only 22% of the papers cover low-level granularity of business processes.

2. Methodology: A majority of papers (57%) does not provide a systematic method for being practiced.
3. Measuring: Measurement is not in the scope of nearly half of the papers (48%). Out of the remaining 52%, a majority (82%) considered quantitative metrics for measurement.
4. Use of formal language: The value of formal presentation of business processes is realised in a majority of the papers (81%).
5. Language dependency: While 51% of the papers consider a specific modelling language for presentation of business processes, 49% of the papers are language-independent.
6. Application: A majority of the papers (88%) focuses on provisioning of generic solutions to be applicable in a variety of situations.

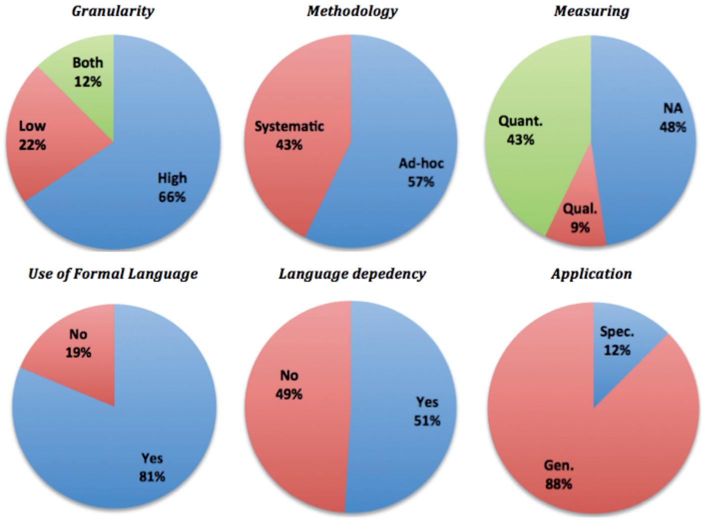

Figure 12 The coverage of units of behaviour for each of the key concepts.

2.4. Discussion and Research Positioning

The concern of this chapter is the complexity of an analysis in the interdisciplinary domain of business processes. The main contribution of this chapter is the establishment of an understanding of different paper in the business process quality domain and positioning of the current research. This chapter facilitates this understanding through a systematic classification and analysis of sixty four papers. This analysis aims to motivate the research community to introduce frameworks, models, metrics, techniques, and supporting tools fostering specification and measurement of real-life business processes at different levels of granularity.

The broad use of formal languages shows the value of modelling for presentation, analysis and measurement of business processes. The plethora of business process modelling languages presents a challenge in communicating cross-organisational business processes where multiple languages are being practiced. This calls for approaches that are language-independent. At the same time, specific modelling languages mandate dedicated syntax and semantics. Many researchers are aware of these requirements. Chapter 3 provides a language-independent abstraction as 'the big picture' in combination with language-dependent approaches for local details.

There is a lack of approaches covering a low-level granularity of business process. Furthermore, specification and measurement of different quality aspects of a business process on the basis of the quality values of its constituent concepts is on demand. The bias toward the high-level granularity is perhaps due to the preference of researchers and management to analyse organisations and business processes as a whole. The quality of business processes as well as its constituent elements is central to achieving high performance organisations (Heidari and Loucopoulos, 2013). Chapter 4 considers a low level of granularity and introduces quality metrics and factors for different business process concepts in different aspects (e.g., availability of an input, or authority of an activity). Six dimensions of performance, efficiency, reliability, recoverability, permissibility, and availability are introduced, covering different aspects of business process quality. Table 2 provides a summary of the concepts, dimensions, and factors covered in this thesis. The table identifies the contributions of the thesis and includes also those papers that are adopted by the thesis.

Covering a wider set of quality aspects and patterns, a set of quality metrics is proposed in Chapter 5 enabling one to evaluate the quality of a business process or a part of it on the basis of the quality values of its individual concepts. Chapter 5 includes six generic control-flow patterns: sequential, parallel with synchronisation, exclusive, inclusive, simple loop, and complex loop. These patterns cover the basic control-flow patterns (van der Aalst et al., 2000a) as well as “structured loop,” “multi choice” and “structured synchronising merge” to cover inclusive, simple loop, and complex loop patterns. Table 3 provides a summary of the quality dimensions and factors and their corresponding patterns covered in this thesis and it also includes those papers that are adopted by the thesis.

Whilst ad-hoc approaches provide flexibility and freedom for the user, systematic approaches offer ways of working in terms of phases, required inputs, expected output, and techniques used. Chapter 4 and Chapter 5 introduce algorithms and frameworks to conduct the computation in a systematic way. These algorithms and frameworks can act as a guideline and stimulates business process modellers and analysts to work in a systematic and generic manner.

Table 2 Quality dimensions and factors and their corresponding business process concepts

		Business Process Concept			
Dimension	Factor	Event	Output	Input	Activity
Performance	**Throughput**	(OMG, 2008) Adopted in the thesis	Introduced in the thesis	Introduced in the thesis	
	Cycle Time				(Cardoso et al., 2002b) Adopted in the thesis
	Timeliness		Adopted in the thesis	(Moeller, 2008)Adopted in the thesis	(Laird and Brennan, 2006)Adopted in the thesis
	Cost			Introduced in the thesis	(Cardoso et al., 2002b)Adopted in the thesis
Efficiency	**Resource Efficiency**				(Oakland, 2004)Adopted in the thesis
	Time Efficiency				Introduced in the thesis
	Cost Efficiency			(Angeles, 2009)Adopted in the thesis	(Angeles, 2009)Adopted in the thesis
Reliability	**Reliableness**				(Laird and Brennan, 2006)Adopted in the thesis
	Failure Frequency				Introduced in the thesis
Recoverability	**Uptime**				Introduced in the thesis
	Downtime				Introduced in the thesis
	Maturity				Introduced in the thesis
Permissibility	**Authority**			Introduced in the thesis	Introduced in the thesis
Availability	**Time to Shortage**			Introduced in the thesis	
	Time to Access			Introduced in the thesis	
	Availableness			Introduced in the thesis	

Given the twenty BPM use cases introduced by (van der Aalst, 2013), the development of BPIMM is positioned as *Merge models (MerM)*, as it focuses on creating new models from existing models. BPM use case *Merge models (MerM)* refers to the scenario where different parts of different models are merged into one model; unlike classical composition, the original parts may be indistinguishable. The computation part of the research is classified as a composite use case, where BPM use cases *design model (DesM)* and *analyse performance based on model (PerfM)* are chained together.

Table 3 Quality dimensions and factors and their corresponding patterns

Dimension	Factor		Sequential	Parallel with syn.	Exclusive	Inclusive	Simple loop	Complex loop
			Pattern					
Performance	Cycle Time	E	(Cardoso et al., 2004) (Zheng et al., 2009) (Zo et al., 2010) (Canfora et al., 2008) (Jaeger et al., 2005) (Tsironis et al., 2010) (Chuang et al., 2002) (Oliveira et al., 2012) Adopted in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) (Zo et al., 2010) (Canfora et al., 2008) (Jaeger et al., 2005) (Tsironis et al., 2010) (Chuang et al., 2002) (Oliveira et al., 2012) Adopted in the thesis	(Cardoso et al., 2002a) (Canfora et al., 2008) (Jaeger et al., 2005) (Zheng et al., 2009) (Tsironis et al., 2010) (Chuang et al., 2002) (Oliveira et al., 2012) Adopted in the thesis	Introduced in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) (Zo et al., 2010) (Tsironis et al., 2010) (Chuang et al., 2002) (Oliveira et al., 2012) Adopted in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) (Zo et al., 2010) (Tsironis et al., 2010) (Chuang et al., 2002) Adopted in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
	Timeliness	E	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
	Cost	E	(Cardoso et al., 2004) (Zheng et al., 2009) (Canfora et al., 2008) (Jaeger et al., 2005) Adopted in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) (Canfora et al., 2008) (Jaeger et al., 2005) Adopted in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) (Canfora et al., 2008) (Jaeger et al., 2005) Adopted in the thesis	Introduced in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) Adopted in the thesis	(Cardoso et al., 2004) (Zheng et al., 2009) Adopted in the thesis

2

			Pattern					
Dimension	Factor		Sequential	Parallel with syn.	Exclusive	Inclusive	Simple loop	Complex loop
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
Reliability	Reliableness	E	(Cardoso et al., 2004) (Canfora et al., 2008) Adopted in the thesis	(Cardoso et al., 2004) (Canfora et al., 2008) Adopted in the thesis	(Cardoso et al., 2004) (Canfora et al., 2008) Adopted in the thesis	Introduced in the thesis	(Cardoso et al., 2004) Adopted in the thesis	(Cardoso et al., 2004) Adopted in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
	Failure Frequency	E	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
Recoverability	UPTime	E	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
	DownTime	E	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
	Maturity	E	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
Permissibility	Authority	E	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis
		M	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis	Introduced in the thesis

E: Estimation – M: Measurement – syn: Synchronisation

Given the above discussion, the research and research questions in this thesis can be positioned with regard to the current state-of-the-art. The identified units of behaviour as well as concepts are utilised for such positioning. Table 4 shows for each concept the research question, research deliverable, and chapter of this thesis.

Table 4 Research positioning

Unit of Behaviour	Concept	Research Question	Research Deliverable	Chapters
Granularity	Low	Can the quality of individual concepts of a business process be computed?	Business Process Concept Quality Evaluation Framework (BPC-QEF) and algorithm	4
	High	Can the quality of a (part of) business process be computed with regard to the results of computing quality of its constituent concepts?	Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm	5
Methodology	Systematic	Can the quality of individual concepts of a business process computed?	Business Process Concept Quality Evaluation Framework (BPC-QEF) and algorithm	4
		Can the quality of a (part of) business process be computed with regard to the results of computing quality of its constituent concepts?	Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm	5
			A set of generic business process patterns	5
Measuring	Quantitative	Can the quality of individual concepts of a business process computed?	Quality metrics for business process concepts	4

2

Unit of Behaviour	Concept	Research Question	Research Deliverable	Chapters
		Can the quality of a (part of) business process be computed on the basis of the results of computing the quality of its constituent concepts?	Computational formulae	5
Application	Generic	Can the quality of a business process be quantitatively computed at different levels of granularity?	All research deliverables	3, 4 and 5
Language dependency	Formal and Language independent	Can concepts of mainstream business process modelling languages be identified?	Business Process Integrating Meta-model	3

In addition to specification of quality aspects, measurement is of importance. There is a tendency toward evaluation via quantitative approaches, as they provide quantitative metrics. Qualitative measurement demands more attention. Stakeholders' views on the quality of a business process can be captured by qualitative methods such as interviews.

Future research should focus on supporting the specification and measurement of different quality aspects in more depth. Each quality aspect has different attributes and requires its own specification with regards to business process concepts. For example, full specification and measurement of security at different levels of granularity calls for papers dedicated to this matter. Different application domains have their own specialities and requirements that should be taken into account in specifying and measuring quality.

The paucity of approaches that tackle specific aspects of quality for a domain (e.g., a specific sector of industry) is a cause for concern because ultimately, a deep analysis of specific requirement, such as security, etc. should be addressed. Future research can also consider extending generic approaches with constructs to tackle specific aspects.

A limitation of this literature review is that the search only considered publications in English. The research could be extended by exploring relevant papers written in other languages. Another limitation is that inclusion decisions could be affected by subjective knowledge about the authors, institutions, journals or the year of publication. The research could be objectified by evaluating the sufficiency and necessity of the concepts as well as its external validity.

2.5. Chapter Summary

Quality is the topic of research in many interrelated disciplines, such as software engineering, service science, industrial engineering, system dynamics, and requirement engineering. The motivation for this chapter is to examine the papers measuring and specifying quality in the business process domain, thus providing a synthesis of the body of work in this area, as well as positioning the thesis. This chapter provided a framework for analysis of business quality approaches based on five concepts: granularity, modelling, methodology, measuring, and application. This chapter assesses sixty four papers from literature according to the framework. The analysis serves as a basis for positioning the thesis as well as articulating a number of directions for future research.

Part II: Proposition

Chapter 3. Business Process Integrating Meta-Model: BPIMM

There is no complete theory of anything.
-Robert Anton Wilson

3.1. Introduction

Business Process Modelling is of core importance for not only business process engineering, analysis and improvement of business processes, but also the development of software systems to support enterprise business processes (Havey, 2005). Linking business process requirements with business process model concepts enables business and IT experts to define their requirements collaboratively at a common abstract level (Loucopoulos, 2000a) during the earliest stage of design and development of information systems. Annotation of business process model concepts with related information artefacts introduces different concepts into the realm of business processes such as goals, rules, patterns, motivation, etc. (Loucopoulos and Katsouli, 1992a, Kavakli and Loucopoulos, 2006).

A proliferation of business process modelling languages (BPMLs) currently exists (Moore and Whinston, 1986) and is a notorious problem for business process management (Mendling et al., 2005). Standardisation has been discussed for more than ten years, yet none of the proposals is commonly accepted as the de facto standard in the industry (Mendling et al., 2005).

Overcoming this problem, different authors propose different approaches mainly to bridge the gap between the design phase (resulting in conceptual models) and the implementation phase (resulting in executable specifications) of business process management. (Hornung et al., 2006) presents an integration methodology to integrate and consolidate heterogeneous business process modelling meta-models, and applies this methodology to the integration of XPDL 2.0 (as an interchange format for BPMN) and BPEL 2.0 (standards for process execution). (Mendling et al., 2005) introduces an interchange format for transferring business process models between tools of different vendors. In a different approach, (van der Aalst et al., 2000a) introduces a workflow patterns framework as a collection of generic and recurring constructs. (La Rosa et al., 2011) proposes an architecture for an advanced process model repository – APROMORE- which offers a rich set of features to maintain, analyse, and exploit the context of process models. In this architecture, a meta-model of canonical process format is provided covering mutual concepts of EPC, BPMN, WF-Net, Protos, YAWL, and WS-BPEL.

Focusing on conceptual modelling of business processes (i.e. design phase), there are increasingly many situations (e.g., distributed projects) where a single BPML is neither practical nor feasible as project participants use different modelling languages (Heidari et al., 2013c). From a theoretical perspective, it is vital to have a clear understanding of the semantics of these approaches, their overlaps, differences and similarities. Only then it becomes possible to systematically and objectively understand the potential contribution of each BPML.

(Mendling et al., 2005) realises the need for a reference model for business process modelling that unifies the different perspectives on modelling business processes. This need is represented in this thesis' research question of "Can the concepts of mainstream business process modelling languages be identified?" To provide an answer to this question, this chapter proposes an abstraction that integrates concepts of seven mainstream BPMLs into a single and integrating meta-model. Section 3.2 discusses the methodology used for development of the integrating meta-model. Section 3.3 presents the business process integrating meta-model. Section 1.1 discusses an ontological analysis of the meta-model against the Bunge-Wand-Weber (BWW) ontology as an upper ontology. Section 3.5 elaborates on application of the integrating meta-model. The chapter concludes in Section 3.6 with a number of observations and suggestions for future work while highlighting the limitations of the thesis.

3.2. Toward an Integrating Meta-Model

A meta-model is an explicit model of the constructs and rules needed to build specific models within a domain of interest. A valid meta-model is an ontology, as its constructs and rules represent entities in a domain. For the ontology introduced in this thesis, the domain is "business process modelling". An ontology makes knowledge explicit, expressing the concepts and relationships between them in a language close to the natural language, fostering a "bridge of understanding" between business and IT experts (Jenz, 2003). Meta-modelling is classified as positivism in epistemology and realism in ontology (Siau and Rossi, 2007). In essence, a meta-modelling approach aims to be independent of an observer's appreciation of the modelling languages, providing an intuitive way to specify modelling languages (Fill and Burzynski, 2009).

Building a domain ontology includes the task of defining basic concepts and structures that are applicable to the target domain (Na et al., 2006). Meta-models are utilised to solve two fundamental types of task, namely design and integration (Karagiannis and Hofferer, 2006). Design involves the creation of meta-models for both the prescriptive definition of not yet existing "subjects" of interest as well as the descriptive modelling of already existing "subjects" of interest. Integration, on the other hand, denotes the application of meta-modelling for bringing together different existing "artefacts" of potentially various kinds, generated using different meta-models.

The approach taken in this thesis is to create a meta-model for the purpose of "integration". The extensible integrating business process meta-model proposed provides a language-independent business process ontology (Figure 13). The BPMLs on which it is based are today's most commonly used mainstream languages: Business Process Modelling Notation (BPMN), Integrated Definition for Function Modelling (IDEF0 and IDEF3), Role Activity Diagram (RAD), Unified Modelling Language Activity Diagram (UML-AD), Structured Analysis and Design Technique (SADT), and Event-driven Process Chain (EPC). Each concept of these BPMLs is mapped onto only one concept in the business process integrating meta-model.

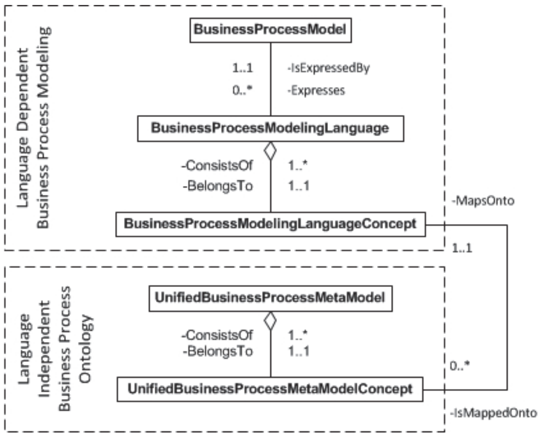

Figure 13 Principle of the language-independent business process ontology (partial view)

According to Karagiannis et al., to be able to define mapping relationships between different models (model-level), a common generic integrating meta-model is needed to which the concepts of the different meta-models correspond. This common integrating meta-model facilitates also a comparison of meta-model concepts with one another (Karagiannis and Hofferer, 2006).

Figure 14 depicts the process of integration with three levels of models: model level, meta-level and integrating-meta level. Different representations of a single business process in the aforementioned BPMLs are shown at the lowest level of abstraction, the model-level, together with their meta-level representations at the second level. An integrating meta-model is presented at the highest level. The integrating meta-model development process includes the steps of (1) generating the individual BPML meta-models, (2) concept mapping, and (3) concept integration.

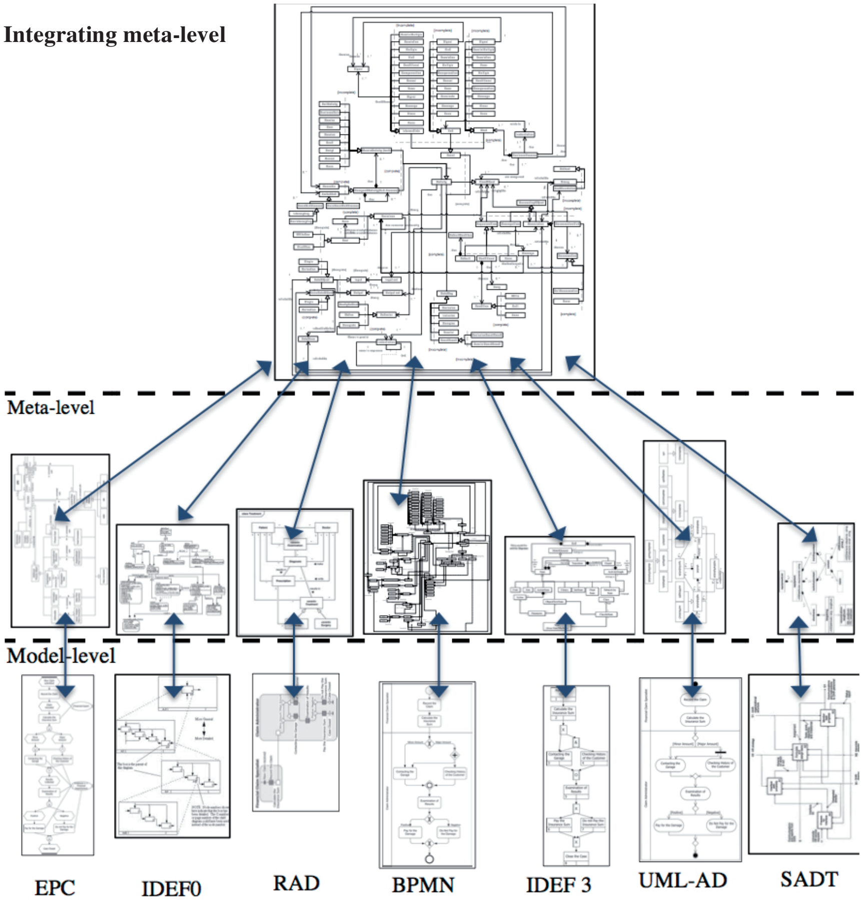

Figure 14 Integrating business process modelling languages

In the first step, meta-models of the BPMLs are generated. Prerequisites for being able to establish a meaningful connection and a mapping at the model-layer are corresponding links at the meta-level. In the second step, concepts are mapped. Mapping implies the definition of concepts of different meta-models that are related (Karagiannis and Hofferer, 2006). The meta-models are heterogeneous, that is, semantically related concepts are captured by different meta-models in different ways, for instance using different names or different structures. In the third step, concepts of these meta-models are analysed and the ones expressing similar aspects of reality are grouped together and mapped to a single concept at the integrating meta-level. The integrating meta-model is expected to be complete in capturing all concepts of the meta-models (Hornung et al., 2006). Integration means to find a logical correspondence between instances of the model layer. The transformational aspect of the integration (Karagiannis and Hofferer, 2006) allows for the next level of mapping, namely mapping the concepts representing the same aspects of reality to a single concept at integrating meta-level.

The main assumption in the integration is that the languages (i.e., BPMLs) in a specific domain (i.e., business process modelling) express similar concepts. This makes it possible to create a common integrated meta-model. Conceptually, this integrating meta-model represents a union of all the concepts found in the BPMLs (Moore and Whinston, 1986). This thesis realises the need to view modelling concepts through a lens that focuses on the ability to express different aspects of a business process rather than detailed semantics and syntax of the language used. In other words, interoperability mapping with semantically identical concepts is not subject of research. Concepts such as activity, action, unit of behaviour and task, represent the executable concept of a business process. These concepts provide the basis for a shared understanding of the domain, which, in turn, fosters communication between experts.

3.3. An Integrating Meta-Model for BPMLs: BPIMM

The concepts of the integrating business process meta-model are categorised into different aspects of a business process, namely: functional, behavioural, organisational, and informational aspects, following the recommendation by (Mili et al., 2006).

Figure 15 depicts the business process integrating meta-model in a UML class diagram, in terms of the main concepts and in relation to different aspects. Figure 16 to Figure 19 classify concepts of the integrating meta-model related to different business process aspects, in addition to inter-aspect relationships (concepts in grey). Concepts of Figure 15 (i.e., main concepts) occurring in Figure 16 to Figure 19 are recognisable by their thicker borders.

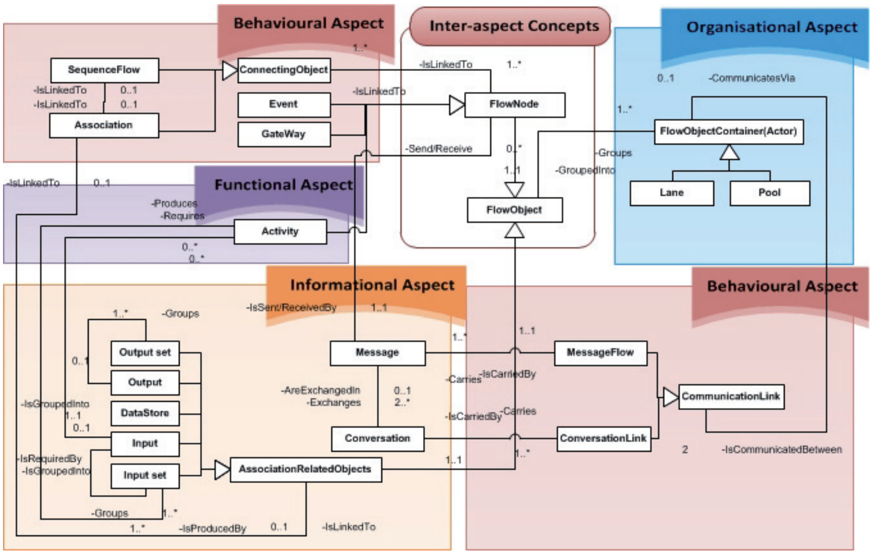

Figure 15 Overview of the business process integrating meta-model in relation to different aspects

Figure 16 depicts the concepts representing the functional aspect. These concepts are executable concepts of a business process. Figure 17 depicts the concepts representing the organisational aspect required to demonstrate executers (actors) of a business process. Figure 18 depicts the concepts representing the behavioural aspect required to demonstrate coordination between different participants as well as the concepts that effect, trigger, or control the flow in a business process. Figure 19 depicts the concepts representing the informational aspect required to demonstrate “inputs” and “outputs” of a business process as physical or data objects as well as “messages” or “conversations” exchanged between different executers. A mapping of different concepts of the meta-model and the BPMLs for different aspects are provided in Table 5. The terminology of the concepts at the integrating meta-level is freely chosen.

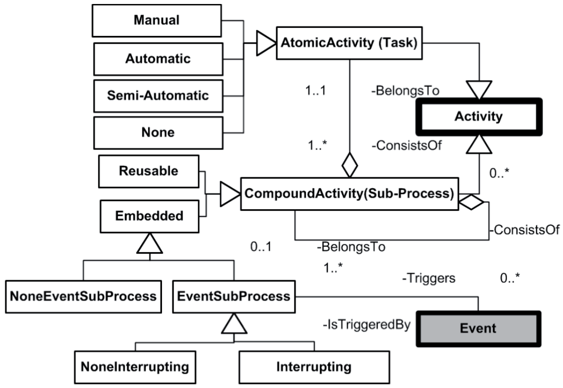

Figure 16 Business process integrating meta-model: Functional aspect

The proposed business process ontology represents an abstraction of the business process concepts. It is universal and not dedicated to a single BPML. The business process ontology clarifies the exact relationships between the concepts. Moreover, it provides an adequate semantic specification prohibiting invalid interpretations by experts in different domains. The ontology also provides an abstraction for elicitation, definition, and documentation of requirements.

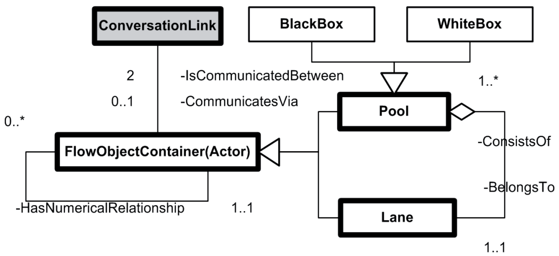

Figure 17 Business process integrating meta-model: Organisational aspect

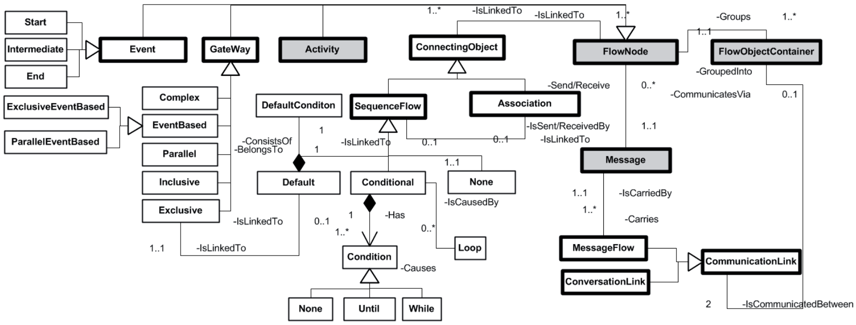

Figure 18 Business process integrating meta-model: Behavioural aspect

This business process ontology -as a repository- can have several applications: (a) to represent models created via deploying any of the constructing modelling languages as its instantiations, (b) to act as a reference between multiple business process modelling approaches of the same project, (c) to provide the basis for developing a repository for managing emerging business process models irrespective of the language used, (d) to be extended to a knowledge base, (e) to facilitate direct implementation, and (f) to act as a reference model, fostering incorporation of stakeholders' requirements.

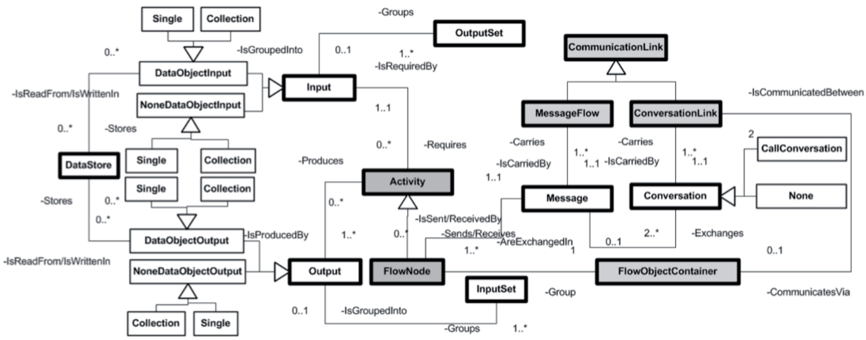

Figure 19 Business process integrating meta-model: Informational aspect

Table 5 Meta-model and the BPMLs' concept mapping

Aspect	Meta-Model	BPMN	RAD	EPC	SADT	UML AD	IDEF0	IDEF 3
Functional	Activity	Activity	Activity	Function	----	Action	Function	Unit of behaviour
Organizational	Flow Object Container	Swimlane	Role	Organizational unit	----	Partition	-----	-----
Informational	Message	Message	----	----	----	Signal	----	----
	Conversation	Conversation	----	----	----	----	----	----
	Signal	-----	----	----	----	----	----	----
	Input	Data Input	----	Information/ material / resource object	Input/ mechanism	Object node	Input/ mechanism	Object
	Output	Data Output	Output/ role deliverable	----	Output	----	Output	----
	Data Store	Data Store	----	----	----	----	----	----
Behavioural	Event	Event	Event/ Triggering Condition	Event	Control	Initial/ Final node	Control	----
	Communication link	Conversation link/Mess-age flow	Role Interaction	Information flow	----	Object flow	----	Object flow link
	Default condition	Default condition	Choice	----	----	Control	Control	----
	Connecting object	Sequence flow/Data association	State	Control flow	Control	Interaction-Control flow	Control	Precedent/ Relational link
	Condition	Condition	Choice	Action Constraint	Control	Condition	Control	-----
	Gateway	Gateway	Choice/ Part refinement	And/XOR/OR	Control	Decision node/ join node	Control	And/XOR/OR Junction

3

3

3.4. Ontological Analysis of BPIMM

Ontological analysis is an established theoretical approach to evaluate modelling languages, in particular to evaluate their expressiveness (i.e. completeness). The ontological analysis requires a representation mapping of the ontological concepts to its corresponding meta-model concepts. This provides useful information for identifying the degree of clarity and completeness of the notation.

Following the justifications by (Recker et al., 2009), the BWW ontology (Wand and Weber, 1993) is chosen in this thesis for an ontological analysis of the meta-model, as: (a) it has specifically been derived with the information systems discipline in mind, (b) it serves as an upper ontology for modelling information systems, and its foundational character and comprehensive scope allow for a wide range of applicability, and (c) there is an established track record of individual studies and a demonstrated usefulness of representational analyses of modelling languages using the representation model, which allows comparison of the results with other studies. The process of using the BWW model as a reference benchmark for the evaluation of the representational capabilities of a modelling language forms the core of the research method of representational analyses (e.g., (Monsalve, 2012)). Representational analyses can be used to make predictions of the modelling strengths and weaknesses of the language, that is, its capabilities to provide complete and clear descriptions of the domain (Recker et al., 2009). The aim is to show how the integrating meta-model is successful in expressing BWW concepts (Table 6).

Note that the integrating meta-model does not include state-oriented concepts that are very situation-specific (Monsalve, 2012). The BWW ontology, in turn, has limited concepts for expressing control concepts (e.g., Loop, gateway).

Table 6 Representational mapping of BWW and the meta-model concepts

No	BWW	Meta-model	No	BWW	Meta-model
1	Things	Flow object container, input, output, signal, data store, message, conversation, condition	**16**	Coupling	Communication link
2	Properties	Attributes of the thing	**17**	System	Flow object container
3	Class	Association related object, flow node, flow object, flow object container, communication link, connecting object	**18**	System composition	----
4	Kind	Sub-types of mentioned classes	**19**	System environment	----
5	State	----	**20**	System Structure	----
6	Conceivable state space	----	**21**	Subsystem	Lane

No	BWW	Meta-model	No	BWW	Meta-model
7	Space law	----	22	System decomposition	----
8	Lawful state space	----	23	Level structure	----
9	Event	Event	24	External event	Event
10	Conceivable event space	----	25	Stable state	---
11	Transformation	Activity	26	Unstable state	
12	Lawful transformation	Sequence flow	27	Internal event	Event
13	Lawful event space	----	28	Well-defined event	End event
14	History	----	29	Poorly defined event	Start event, intermediate event
15	Acts on	Communication link			

3

3.5. Demonstration of Applicability

This section demonstrates applicability of the business process ontology as a repository able to represent models by the BPMLs. The business process of "processing of automobile insurance claim" is adapted from (Korherr, 2008). The business process is modelled in BPMN, RAD, IDEF3, UML-AD, and EPC by (Korherr, 2008). Protégé (Gennari et al., 2003) is used to create the instantiations. Instantiations of the meta-model via Protégé semantically match the individual models. Due to space limitations, Protégé presentations of the models are not included and will be available in request. Protégé supports creating ontologies based on Web Ontology Language (WOL) rules; it supports a graphical representation that facilitates reviews by non-technical domain experts. This supports communication between business and IT experts. In addition, it provides a means with which to express stakeholders' requirements in a consistent and machine-processable fashion and facilitates synchronisation between requirements and business process concepts.

Table 7 depicts the similarities between concepts with regard to different aspects, such as activity (BPMN, RAD), action (UML-AD), function (EPC), and unit of behaviour (IDEF3). Not only does this approach show similarities, it also gives an overview of the differences. Note that some of the notations lack a distinctive concept for a particular purpose; for instance, executer in the organisational aspect represented by instances like "Financial Expert" is not covered by IDEF3 concepts, as there is no "concept" introduced with the purpose of demonstrating executers of an activity in IDEF3.

Table 7 Comparison between BPMLs and the integrating meta-model concepts in the example

No	Meta-Model	Aspect	BPMN	RAD	EPC	UML AD	IDEF 3
1	Message	Informational	Message	----	----	----	----
2	Message Start Event	Behavioural	Message Start Event	Event	Start	Initial Node	----
3	None Sequence Flow	Behavioural	None Sequence Flow	State	Control Flow	Control Flow	Precedence Link
4	Activity	Functional	Activity	Activity	Function	Action	Unit of Behaviour
5	Message Flow	Behavioural	Message Flow	Role Interaction	Information Flow	Object Flow	----
6	Exclusive Gateway	Behavioural	Exclusive Gateway	Choice	XOR Split	Decision Node	XOR Junction
7	Conditional Sequence Flow	Behavioural	Conditional Sequence Flow	----	----	----	Constraints Precedence Link
8	Condition	Behavioural	Condition	Choice	Event	Condition	Control
9	Parallel Gateway	Behavioural	Parallel Gateway	Part Refinement	And Join/Split	Fork/Join Node	AND Junction
10	Inclusive Gateway	Behavioural	Inclusive Gateway	----	XOR Join	Merge Node	XOR Junction
11	Terminate End Event	Behavioural	Terminate End Event	Event	End Event	Final Node	-----
12	White box Pool	Organizational	White box Pool	Role	Organizational Unit	Partition	----

One of the applications of a business process ontology as a repository is to act as a reference to support explication of requirements. An ontology can describe both functional and non-functional requirements (Jenz, 2003). One of the applications of this business process ontology is that stakeholders can have their desired requirements defined at a higher level (meta-model) than specific business process specifications. The business process ontology, enriched with the desired requirements, can act as a reference model for creation of future business processes.

Figure 20 provides a partial view of the instantiation of the meta-model and incorporation of requirements into the business process concepts (Meta-level) and instances (Model). Figure 20 shows that a desired requirements can be incorporated not only into the business process concepts at the meta-level but also into instantiations using Protégé. Incorporation of requirements can facilitate communication between different stakeholders. It can also act as a guideline independent of the developer's appreciations. This can facilitate efficiency, integrity, consistency, and reusability and reduces human mistakes, etc.

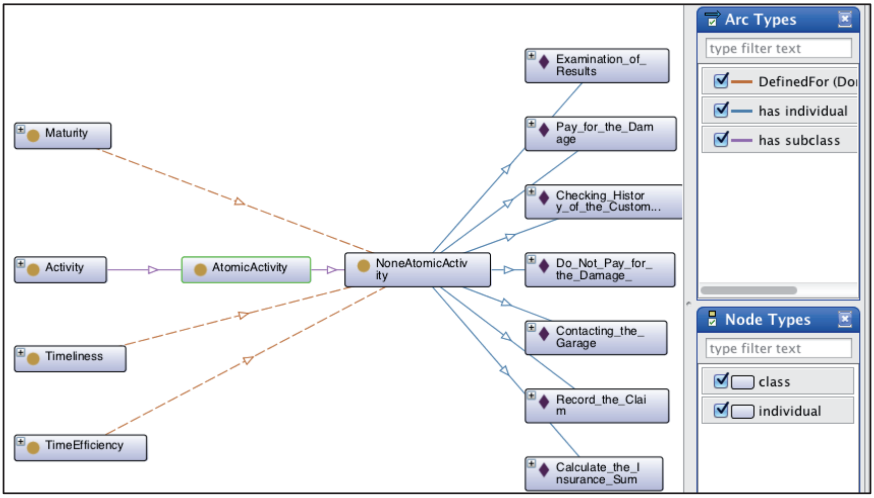

Figure 20 An example of instantiation and incorporation of quality requirements

3.6. Discussion and Future Work

This chapter concludes that a language-independent and multiple-source business process integrating meta-model is needed to provide a comprehensive recognition of business process concepts. This chapter proposes a language-independent business process integrating meta-model based on an integration of the concepts of seven mainstream BPMLs. This provides an answer to this thesis' research question of "Can the concepts of mainstream business process modelling languages be identified?" Presentation of business process concepts in a meta-model supports interaction with, and between, non-technical business experts and information system experts in elicitation, definition, and documentation of business processes. In the areas of requirement engineering and software engineering, the meta-model is the basis for realising business process concepts and enriching them with requirements at the earliest stage of software and information systems development in a collaborative manner. Moreover, language independency of the approach and extensive enrichment possibilities also allow for further application in many different areas such as object-oriented system engineering.

The ontological analysis of the integrating meta-model against the BWW ontology for representational analysis is conducted in this thesis. This provides a view on not only consensus deficiencies of the BPMLs in representing real world constructs, but also the concepts of the integrating meta-model that cannot be covered by BWW concepts.

There are limitations of this approach. First, it is based on mainstream BPMLs, so not all BPMLs are studied in this thesis research. Future research should incorporate an increasing number of BPMLs. Second, there is the issue of semantic loss when a BPML is mapped onto the integrating meta-model. This semantic loss and the way to ameliorate any issues arising from this is also a line of research in the future.

This work can be extended in several directions. One way of comparing methods is to use their meta-models as a basis for analysis (Siau and Rossi, 2007). Comparative analysis of BPMLs is also discussed in the work of (Recker et al., 2009). Attempts to use a common meta-modelling language for evaluating methods concentrates on mapping methods to some 'super-method', or comparing models of methods by identifying their common parts (Lonjon, 2004). Considering the language-independency of the proposed meta-model, this integrating meta-model can be used as a reference model for comparative analysis of BPMLs. Moreover, the proposed integrating meta-model can also act as a basis for the development of future BPMLs as well as enhancement of the existing ones. Another direction of future work is to evaluate the correctness of the integrating meta-model as well as to empirically evaluate the theoretical ontological analysis of the business process meta-model. Developing an algorithm for conversion between different business process models is another direction for future work.

Chapter 4. Business Process Concept Quality Computation: BPC-QC

4

Science is wonderfully equipped to answer the question "How?"
but it gets terribly confused when you ask the question "Why?"
-Erwin Chargaff

4.1. Introduction

Arguably the most significant issue in systems development is to understand requirements and transforming them without information loss into a semantically rich specification, from which various types of software artefacts can be derived (Loucopoulos and Karakostas, 1995). Currently, enterprises are described in terms of business process models. Linking business process quality requirements with business process concepts enables IT and business experts to define their requirements collaboratively at a common abstract level during the earliest stage of design and development of information systems (Heidari et al., 2013b).

Business process modelling is an important part of information systems design as well as of any business engineering or reengineering activity. Business process modelling languages provide standard ways of presentation and communication between different stakeholders. A business process model is the externalisation of the conceptualisation of some parts of an object world that deal with those aspects that pertain to the way business transactions are carried out and supported by an information system. This chapter deals with an essential issue in this context, namely the evaluation of the quality of business process concepts through business models. The need is reflected in the research question of "Can the quality of individual concepts of a business process be computed?" and the two investigative questions: "Can the quality factors for key business process concepts be identified?" and "Can the metrics for measuring quality factors of key business process concepts be defined?"

To this end, this chapter is organised as follows. In Section 4.2, the business process concept quality evaluation framework (BPC-QEF) is introduced in terms of the main constructs of the methodology and the business process concepts upon which quality dimensions and factors are defined. Section 4.3 focuses on the quality dimensions and factors and their metrics of business process concepts. In Section 4.4, BPC-QEF is illustrated through an example. Section 1.1 provides a reflective discussion on BPC-QC, its limitations and its potential future developments.

4.2. Business Process Concept Quality Evaluation Framework: BPC-QEF

The section proposes a business process concept quality evaluation framework (BPC-QEF) with both a methodology and an ontology, using conceptual modelling. One of the advantages of using conceptual modelling is that it captures the semantics of an application through the use of a formal notation, and this has long proved to be of significant help in a variety of domains. For example, requirements can be formally defined (Loucopoulos, 1995), business rules can be externalised from applications (Loucopoulos and Katsouli, 1992b), information systems designed (Tsalgatidou and Loucopoulos, 1990), and such designs may be validated using visualisation techniques (Lalioti and Loucopoulos, 1993).

In BPC-QEF, concepts and interrelations between concepts are defined formally in conceptual meta-models, represented as a UML class diagram (OMG, 2003). In BPC-QEF, a business process is analysed for its quality through its ***Business Process Model***, expressed in some ***Business Process Modelling Language*.** The plethora of different BPMLs, however, presents a dilemma regarding the utility of the quality framework. Should the framework be dedicated to a single, and perhaps popular, modelling language (e.g., BPMN), or should it be general enough to be used universally? Although, there are trends pointing towards some form of standardisation, there is still a long way before reaching the state of a standard BPML. Furthermore, there are practical situations where a common approach is neither feasible nor desirable; for example, in inter-enterprise integration efforts, where different approaches and cultures prevail, it is usually the case that BPMLs are used according to local practices. If BPC-QEF is to be tied to a specific BPML, then its applicability would be limited to that particular language.

One of the objectives of BPC-QEF is to be independent of any BPML. This is achieved by viewing quality through a lens that focuses on the semantics of the application rather than the syntax of the BPML used to describe the application, hence the development of the ***Integrating Business Process Meta-Model***, details of which are given in Chapter 3. This rationale is shown schematically in Figure 11.

The ***Integrating business Process Meta-model*** is developed, based on a mainstream ***Business Process Modelling Language***: Business Process Modelling Notation (BPMN), Integrated Definition for Function Modelling (IDEF0 and IDEF3), Role Activity Diagram (RAD), Unified Modelling Language Activity Diagram (UML-AD), Structured Analysis and Design Technique (SADT), and Event-driven Process Chain (EPC). The business process concepts to which the quality evaluation is applied are defined by pragmatic considerations rather than a desire to develop another abstract definition of business process modelling.

The ***Quality Meta-Model*** itself constitutes the focus of this section, and its details are shown in Figure 21. The ***Quality Meta-Model*** encompasses a set of concepts that link non-functional requirements to specific facets of business processes, their quality factors, and corresponding metrics. This meta-model determines the concepts used in BPC-QEF and guides the systematic process within BPC-QEF. Specifically, the process is described as follows:


```
ALGORITHM.
BEGIN
    A stakeholder defines Quality requirements in natural language
        FOR each quality requirement
            Define the business process referenced in the quality requirement;
            Define a quantified expression as quality objective;
                FOR each quality objective
                    Determine the business process concept to which quality is referred;
                    Define quality factor for this concept;
                    Define the metric to be applied to this quality factor;
                ENDFOR
            Query the quality of the business process as a question;
                FOR each question
                    Identify the business process concept being queried;
                    Identify quality factor for this concept;
                    Apply the metric to be applied to this quality factor;
                    Obtain result of measurement;
                ENDFOR
            Compare the result of measurement with quality objective;
            Define degree of satisfying quality objective;
        ENDFOR
    Return the results to stakeholder;
END
```

Figure 21 shows that a ***Non-Functional Requirement*** (e.g., “The use of leather should be efficient”) is associated with a ***Business Process*** (e.g., “Produce a wallet”). A ***Non-Functional Requirement*** is expressed by a ***Stakeholder***[1] (e.g., a production line manager). The ***Functional Requirement*** is operationally queried by a ***Quality Question*** (e.g., “What is the current efficiency of using leather in the cutting activity?”). A ***Quality Question*** essentially is a query on the ternary relationship of ***Business Process Concept***, ***Quality Factor***, and ***Quality Metric***. This is shown as the objectified relationship ***Result*** related to ***Quality Question***.

1 BPC-QEF deals with one non-functional requirement expressed by one stakeholder at a time.

A ***Business Process*** is constructed out of ***Business Process Concepts*** (e.g., Activity). A business process ***Quality Factor*** (e.g., resource efficiency) is an inherent property of a ***Business Process Concept*** that can be measured quantitatively or qualitatively by a ***Quality Metric*** (e.g., formula for computing efficiency of using leather). A business process ***Quality Dimension*** (e.g., efficiency) is defined as a category of business process ***Quality Factors*.** Similar to (Peralta et al., 2009), ***Quality Factors*** are grouped into ***Quality Dimensions***, each representing an aspect of business process concept quality (e.g., performance, efficiency, and those colloquially referred to a "-ilities").

4

The ***Quality Objective*** (e.g., "The efficiency of using leather in the cutting activity should be more than 95%") is a way of quantitatively analysing the ***Non-Functional Requirement*** and is defined as some ***Target Quality Measure (95%<=)*** which is shown as the objectified relationship of three concepts namely those of ***Quality Factor*** (e.g., leather efficiency) for a particular ***Business Process Concept*** (e.g., cutting activity) and a corresponding ***Quality Metric***.

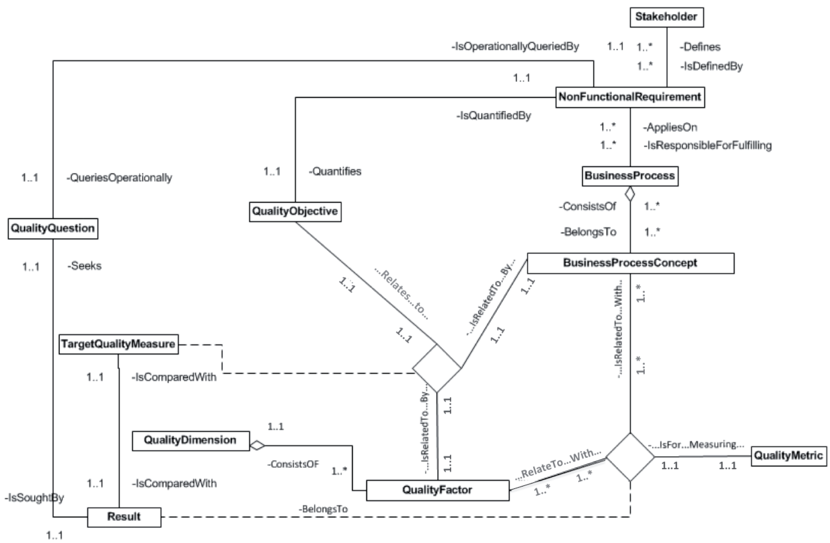

Figure 21 The quality meta-model

The gap between the stated ***Quality Objective*** and the observed current performance through the ***Quality Question*** is shown through the relationship of ***Target*** and ***Result***. Several ***Quality Metrics*** can be associated for the same ***Quality Factor***, as there might be several ways for evaluation. Different stakeholders can introduce different sets of metrics based on their needs (Kedad and Loucopoulos, 2011).

4.3. Quality Factors and Metrics

Four business process concepts act as the foci for quality dimensions and their associated quality factors: **event**, **output**, **input**, and **activity**. This list is not intended to be exhaustive. Following definitions are provided for these concepts. The following quality dimensions are considered: **performance, efficiency, reliability, recoverability, permissibility,** and **availability.** Again, this list is not intended to be exhaustive, but it represents an important set of quality factors for the majority of business processes.

Figure 22 is derived from Figure 3 and depicts a positioning of business process concept quality computation in a model-driven architecture. As can be seen, estimation takes place at the model-level (business process concept type level) where the required data are estimated. At the runtime/data level (business process concept instance level), measurement takes place where required data are acquired through observation.

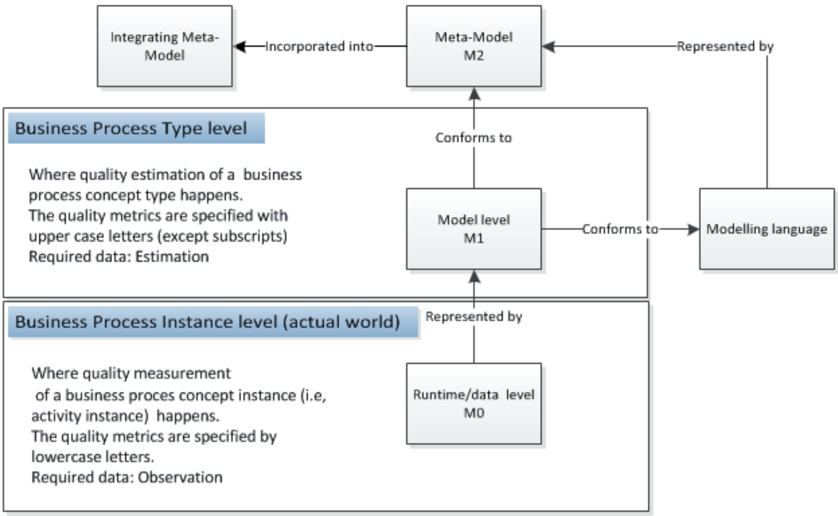

Figure 22 Positioning BPC-QC in a model driven architecture

Table 8 presents definitions of terms used throughout this section.

Table 8 Definitions of terms in BPC-QC

Term	Definition (estimation)	Term	Definition (measurement)
A	Activity type	*a*	Activity instance
E	Event type	*e*	Event instance
I	Input type	i	Input instance
O	Output type	o	Output instance

The computation provides data upon which statistical operations can be implemented for analysis purposes. The selection of the operation depends on the frequency of the instance and its context (e.g., building a bridge versus mass production of the front suspension of a car) and the nature of the quality factor.

4.3.1. Performance

In (OMG, 2008) performance makes reference to the **Timeliness** aspects of how software systems behave, and this includes different types of quality of service characteristics, such as **Latency** and **Throughput**. Considering the role of business processes in transforming inputs to outputs, factors such as **Throughput**, **Cycle Time**, **Timeliness** and **Execution Cost** are considered the quality factors of performance.

Throughput

Throughput in general means the amount of work, people, or things that a system deals with in a particular period of time and this factor is defined for event[1], input, and output . **Event Throughput** refers to the number of event instances handled during an observation interval by an activity. This value determines a processing rate (OMG, 2008). Besides **Event Throughput**, also **Input Throughput** and **Output Throughput** are introduced. Depending on the context, different units can be defined for input and for output. **Input Throughput** calculates the amount of inputs instances processed by an activity in a time

[1] An event (BPMN V2.0) is something that "happens" during the course of a Process. These Events affect the flow of the Process and usually have a cause or an impact and in general require or allow for a reaction. This notion of event is different from the notion of event in process mining VAN DER AALST, W. M. P. & DUSTDAR, S. 2012. Process Mining Put into Context. *IEEE Internet Computing,* 16**,** 82-86.

interval. **Output Throughput** indicates the amount of output instances delivered by an activity in a time unit. The philosophy behind a **Throughput**-based strategy usually demands that business processes deliver the most value as rapidly as possible. This can be regarded as a competitive advantage of a business process, especially in the ones that are related to mass processing of an event or an input or delivery of an output. Thus, the objective function for a **Throughput** is to increase it. Formulae for **Throughput** calculation and objective function are defined as follows:

M[1]	$th(e) = \frac{n(e)}{t}$	th(e) = Throughput of an event (number of an event instances handled in a time unit) n(e) = Number of an event instances handled in "t" duration t = observation interval duration
M	$th(i) = \frac{n(i)}{t}$	th(i) = Throughput of an input (amount of an input instances processed in a time unit) n(i) = amount of an input instances handled in "t" duration t = observation interval duration
M	$th(o) = \frac{n(o)}{t}$	th(o) = Throughput of an output (amount of an output instances delivered in a time unit) n(o) = amount of an output instances handled in "t" duration t = observation interval duration
M	OF: Max th(e) OF: Max th(i) OF: Max th(o)	OF= Objective Function

Cycle Time

Time is a common and universal measure of performance. It can be defined as the total time needed by an activity to transform a set of inputs into defined outputs (Cardoso et al., 2002b). The first measure of time is activity **Cycle Time**. Activity **Cycle Time** corresponds to activity instance execution time (Cardoso et al., 2002b). The activity **Cycle Time** can be subdivided into two major components: **Delay Duration** and **Process Duration**. **Delay Duration** can be subdivided into **Queue Duration**, **Synchronisation Duration** and **Setup Duration** (Cardoso et al., 2002b). The objective function for **Cycle Time** is to reduce it. Formulae for **Cycle Time** calculation and objective function are defined as follows:

[1] "M" denotes measurement. Formulae for specifying measurement at the instance level are presented with lowercase letters.

4

M	t(a) = dd(a) + pd(a)	t(a) = cycle Time duration of an activity dd(a) =Delay Duration of an activity pd(a)= Process Duration of an activity
M	dd(a) = qd(a) + sd(a) + syd(a)	dd(a) = Delay Duration of an activity qd(a)= Queue Duration of an activity sd(a)= Setup Duration of an activity syd(a)= SYnchronisation Duration of an activity
M	of: Min t(a)	of= Objective Function
E[1]	T(A) = DD(A) + PD(A)	T(A) = cycle Time duration of an activity DD(A) =Delay Duration of an activity PD(A)= Process Duration of an activity
E	DD(a) = QD(A) + SD(A)+SYD(A)	DD(A) = Delay Duration of an activity QD(A)= Queue Duration of an activity SD(A)= Setup Duration of an activity SYD(A)= SYnchronisation Duration of an activity
E	OF: Min T(A)	OF= Objective Function

Timeliness

According to (Moeller, 2008), the quality of information includes several items, such as having information timely and available when required. This requirement is translated to response time. The response time of a system is the interval between a user's request and the corresponding system's response (Laird and Brennan, 2006). **Timeliness** simply means timely convenience (Fellbaum, 1998) and this factor is defined for input, output and activity. **Input Timeliness** indicates having the input timely and available when it is required (Moeller, 2008) and consequently **Activity Timeliness** refers to executing an activity with no delay. **Output Timeliness** indicates having the output timely and available when it is required. **Timeliness** has a negative relationship with delay in delivering an input or input or executing an activity. Obviously, the objective function for **Timeliness** is to increase it. Formulae in **Timeliness** calculation and objective functions are defined as follows:

---

[1] "E" denotes estimation. Formulae for specifying estimation at the type level are presented with uppercase letters.

M	ti(i) = −d(i) d(i) = dt(i) −ut(i)	ti(i)= Timeliness of an input d(i)= delivery Delay of an input dt(i)= Delivery Time of an input ut(i)= delivery dUe Time of an input
M	ti(o) = − d(o) d(o) = rt(o) − ut(o)	ti(o)= Timeliness of an output d(o)= Delay of an output rt(o)= Response Time of an output ut(o)= dUe Time of an output
M	ti(a) = − d(a) d(a) = rt(a) − ut(a)	ti(a)= Timeliness of an activity d(a)= Delay of an activity rt(a)= Response Time of an activity ut(a)= dUe Time of an activity
M	of: Max ti(i) of: Max ti(o) of: Max ti(a)	of=Objective Function
E	TI(I) = −D(I) D(I) = DT(I) −UT(I)	TI(I)= Timeliness of an input D(I)= delivery Delay of an input DT(I)= Delivery Time of an input UT(I)= delivery dUe Time of an input
E	TI(O) = − D(O) D(O) = RT(O) − UT(O)	TI(O)= Timeliness of an output D(O)= Delay of an output RT(O)= Response Time of an output UT(O)= dUe Time of an output
E	TI(A) = − D(A) D(A) = RT(A) − UT(A)	TI(A)= Timeliness of an activity D(A)= Delay of an activity RT(A)= Response Time of an activity UT(A)= dUe Time of an activity
E	OF: Max TI(I) OF: Max TI(O) OF: Max TI(A)	OF=Objective Function

Cost

Cost is defined as the amount of money needed to buy, pay for, or do something, and this quality factor is defined for input and activity; **Activity Cost** represents the cost associated with the execution of an activity in a business process . **Cost** is an important factor, since organisations need to operate according to their financial plan. **Activity Cost** is the cost incurred when an activity is executed (Cardoso et al., 2002b). **Activity Fixed Cost** as well as **Activity Variable Cost** should be considered as elements of **Activity Cost** in the calculation. Besides activity cost, **Input Acquisition Cost** is also considered in cost calculations of a business process. **Input Acquisition Cost** corresponds to the amount of money spent for acquisition of the input. **Input Acquisition Fixed Cost** and **Input Acquisition Variable Cost** are considered as elements of **Input Acquisition Cost** in the calculation. The objective function for all types of **Cost** is to reduce it. Formulae for **Execution Cost** calculation, objective function and objective function are defined as follows:

M	c(a) = fc(a) + vc(a)	c(a)= Cost of an activity fc(a)= Fixed Cost of an activity vc(a)= Variable Cost of an activity
M	c(i) = fc(i) + vc(i)	c(i) = acquisition Cost of an input fc(i)= Fixed acquisition Cost of an input vc(i) = Variable acquisition Cost of an input
M	of: Min c(a) of: Min c(i)	of= Objective Function
E	C(A) = FC(A) + VC(A)	C(A)= Cost of an activity FC(A)= Fixed Cost of an activity VC(A)= Variable Cost of an activity
E	C(I) = FC(I) + VC(I)	C(I) = acquisition Cost of an input FC(I)= Fixed acquisition Cost of an input VC(I) = Variable acquisition Cost of an input
E	OF: Min C(A) OF: Min C(I)	OF= Objective Function

4.3.2. Efficiency

Efficiency in general means skilfulness in avoiding wasted time and effort (Fellbaum, 1998). In this thesis, **Efficiency** as a quality dimension includes **Resource Efficiency** (non-financial resources), **Time Efficiency**, and **Cost Efficiency** as its quality factors.

Input (Resource Efficiency)

Utilisation is considered as one of the quality factors for resources (Oakland, 2004). This can be translated to a **Resource Efficiency** factor of an activity instance, which shows how successful an activity instance is in avoiding wasted resources. As this quality factor is calculated in terms of the percentage of planned resource utilisation out of actual resource utilisation, the objective function is to have **Efficiency** more than 100%. This means that either utilisation is equal to the planned amount or less than the planned amount. In the execution of an activity (instance) different resources can be utilised. Hence in computation of overall resource efficiency of an activity, efficiency of each resource utilisation should be incorporated. In doing so, each resource is associated with a weight (w) demonstrating the relative value of that resource in comparison to other resources while $\sum_{k=1}^{n} w_k = 1$. Measuring weights is not a straightforward task and w_k can be determined through implementing different techniques (e.g., (Saaty, 1980, Leskinen, 2000, Mon et al., 1994)), The Formulae for activity **Resource Efficiency** calculation and objective function are defined as follows:

M	$er_k = \frac{pr_K(a)}{ar_K(a)} \times 100$	$er_k(a)$= Resource "k" Efficiency of an activity $ar_k(a)$= Actual Resource "k" utilisation of an activity $pr_k(a)$= Planned Resource "k" utilisation of an activity
M	$er(a) = \left[\sum_{k=1}^{n} w_k \left(\frac{er_K(a)}{er_K(a)}\right)\right] \times 100$ $\sum_{k=1}^{n} w_k = 1$	er(a)=activity Resource Efficiency n=number of resources w_k= Weight of resource "k" $ar_k(a)$= Actual Resource "k" utilisation of an activity $pr_k(a)$= Planned Resource "k" utilisation of an activity
M	of: $er(a) \geq 100$	of= Objective Function

Time Efficiency

For executing any activity in a business process, the goal is to spend not more than the planned time for its execution. This quality factor is reflected in **Activity Time Efficiency**. **Activity Time Efficiency** indicates how successful an activity is in avoiding wasted time. The formulae for **Time Efficiency** calculation and objective function are defined as follows:

4

M	$et(a) = \frac{pt(a)}{t(a)} \times 100$	et(a)= Time Efficiency of an activity t(a) = cycle Time duration of an activity pt(a) = Planned Time duration of an activity
M	of: $e(a) \geq 100$	of= Objective Function

Cost Efficiency

In the area of manufacturing, process **Cost Efficiency** is measured in terms of total processing cost. The aim is to develop, produce, and deliver products at the lowest possible cost (Angeles, 2009). **Cost efficiency** as a quality factor is specified for activity and input concepts. **Activity Cost efficiency** shows how successful an activity is in avoiding wasted budget**. Input Cost efficiency** indicates whether the acquisition of the input is within the determined budget. As these quality factors are calculated in terms of the percentage of planned cost out of actual cost, the objective function is to have **Efficiency** more than 100%. This means that either the instance required less than or equal to the planned budget. Formulae for **Cost Efficiency** calculation and objective functions are defined as follows:

M	$ec(a) = \frac{pc(a)}{c(a)} \times 100$	ec(a)= Cost Efficiency of an activity c(a)=actual Cost of an activity pc(a)= Planned Cost
M	$ec(i) = \frac{c(i)}{pc(i)} \times 100$	ec(i)= Cost Efficiency of an input c(i)= actual acquisition Cost of an input pc(i)=Planned acquisition Cost of an input
M	of: $ec(a) \geq 100$ of: $ec(i) \geq 100$	of= Objective Function

4.3.3. Recoverability

The **Recoverability** of a system is the capacity to re-establish its adequate level of performance with minimum loss of data (OMG, 2008). This quality dimension is related to an activity and encompasses **Down Time**, **UPTime** and **Maturity** as its quality factors.

DownTime

There are times that failures happen in executing an activity. When a failure happens, there is a need to overcome these failures to have the activity run again. The duration that an activity cannot be enacted until the failures are recovered is called **DownTime**. The aim is to shorten this time as much as possible. The formula for **DownTime** computation and its objective function -developed in this thesis- are defined as follows:

M	dot(a) = $\sum_{i=1}^{n} tor_i(a)$	dot(a) = DownTime of an activity $tor_i(a)$= Time Of Recovery of an activity from failure i n= number of failures during an activity
M	of: Min [dot(a)]	of= Objective Function
E	DOT(A) = $\sum_{i=1}^{n} TOR_i(A)$	DOT(A) = DownTime of an activity $TOR_i(A)$= Time Of Recovery of an activity from failure i n= number of failures during an activity
E	OF: Min [DOT(A)]	OF= Objective Function

UPTime

There are times that an activity is running without any failure. There might be times that a business process or a part of it cannot be executed due to a failure in occurrence of an activity. **UPTime** is considered as the duration that an activity is running without any failure. The aim is to have **UPTime** to be as long as possible. The formulae for **UPTime** and objective function -developed in this thesis- are defined as follows:

M	upt(a) = t(a) − dot(a)	upt(a)= UPTime of an activity t(a) = cycle Time of an activity dot(a)= DownTime of an activity
M	of: Max [upt(a)]	of= Objective Function
E	UPT(A) = T(A) − DOT(A)	UPT(A)= UPTime of an activity T(A) = cycle Time of an activity DOT(A)= DownTime of an activity
E	OF: Max [UPT(A)]	OF= Objective Function

Maturity

Maturity is the state or quality of being fully grown or developed. **Maturity** is the percentage of the time that an activity instance is executed without failure (expressed as a percentage). The aim is to increase **Maturity**. To improve **Maturity**, increasing the length of execution of an activity without failure and decreasing the time required for recovering from a failure are required. Formulae for **Maturity** calculation and objective function -developed in this thesis- are defined as follows:

M	m(a) = [upt(a)/(upt(a)+dot(a))]×100	dot(a) = DownTime of an activity upt(a) = UPTime of an activity
M	of: Max [m(a)]	of= Objective Function
E	M(A) = [UPT(A)/(UPT(A)+DOT(A))]×100	DOT(A) = DownTime of an activity UPT(A) = UPTime of an activity
E	OF: Max [M(A)]	OF= Objective Function

4.3.4. Reliability

Failure in this context is defined as the inability of an activity or a process to continue its execution or to be executed as expected. Failures can be just annoying or catastrophic. One failure can be corrected within seconds while another requires weeks or even months. Complicating the issue even further, the correction of one failure may in fact cause other errors that ultimately result in other failures. An important quality attribute of a business process or an activity is the degree to which it is reliable to perform its intended function without failure. Measurement and estimation of this attribute should be of concern to designers, analysts and stakeholders. Thus, it is vital to be able to keep track of the failures occurred or to have an idea of the probability of failure occurrence.

The basic objective in **Reliability** engineering is to predict when a system will fail, be it a probe to Mars, a website, a banking transaction, or a space shuttle (Laird and Brennan, 2006). Therefore, with regard to the importance of business processes in delivering business goals, this quality dimension should be considered, defined and calculated for a business process. **Reliableness** and **Failure Frequency** are defined for activity as the quality factors of Reliability dimension. Reliableness indicates the probability of execution without failure and therefore provides a view of the future while the frequency of failure can be estimated as well as measured.

Reliableness

Reliableness is the quality of being dependable or reliable (Fellbaum, 1998). (Garvin, 1987) specifies **Reliableness** as the probability of a product working fault-free within a specified time period. According to this view, this quality factor can be regarded as a functional quality factor. For software as a product, (Moeller, 2008) considers **Reliableness** as the capability of the software product to maintain a specified level of performance when used under specified conditions. According to this view, this quality factor can be regarded as a non-functional requirement for business processes. Combining those views, **Reliableness** of an activity is defined in this thesis as the **probability** that an activity is executed **without failure** in a **given environment** and **during a specified period of time.** This definition is adopted from (Laird and Brennan, 2006) for **Reliableness** of software. In (Heravizadeh, 2009), **Reliableness** is defined as the capability of the function to be in a state to perform under stated conditions at a given point in time. Regarding the statement by (Laird and Brennan, 2006) it can be said that, despite that this definition may seem obvious or even trivial, there is a need for a further clarification: business process stakeholders determine whether or not they consider a business process to be performing well enough, and that may depend on their own individual expectations. Therefore, the rest of this section is based on the definition given by (Laird and Brennan, 2006) for the area of software, adapted to the area of business processes.

The first interesting term is **probability**. The formulae specified for calculating **Reliableness** are based on probability laws. The next important term is **without failure**. It is necessary to define more clearly what is meant by a failure. For a simple business process like answering a telephone call, dropping a call might not be considered a failure, but crashing the network might be. **In a given environment** is an extremely important term. A business process, which is designed for a normal situation, acts differently in a crisis situation. Finally, consider the term **during a specified period of time.** A requirement for an activity to be executed for having a **Reliableness** of 99.999% for the duration of two seconds and a similar requirement for the duration of two years are entirely different.

Thus, stakeholders should come to an agreement for an activity on (a) the notion of failure in execution of an activity, (b) the environment in which a reliable execution is expected, and (c) a time span that a certain reliableness is expected.

Formulae for reliability are defined based on probability laws. In this definition, it is assumed that the reliableness of an activity will not improve over time. **Reliableness** as a probability can have a uniform or random distribution. In a uniform distribution, the activity may fail at any time interval **during a specified period of time** with equal probability. In a random distribution (also called an exponential distribution), obviously, failures are apt to occur randomly over time; they are independent of the past events. That is, the probability of failure is equivalent for each time period t, given that the system has not failed before time t. Thus, the equation is:

$$f(t) = \lambda e^{-\lambda t}$$

λ is also called the instantaneous failure rate, or hazard rate, and is the reciprocal of the Mean-Time-To-Failure (MTTF). That is:

$$\lambda = 1/MTTF$$

Note that f(t) never reaches 0, according to mathematical logic.

If there is a failure, with n different failure points of t_1 through t_n, then:

$$MTTF = \sum_{i=1}^{n} t_i/n$$

If there is a probability distribution f (t), then MTTF = expected value of f (t), which is just:

$$MTTF = \int_0^{\infty} t f(t) dt$$

For the exponential distribution:

$$MTTF = \int_0^{\infty} \lambda t e^{-\lambda t}\, dt = 1/\lambda$$

Like any integral rules, the probability of failure during a time interval t_1 and t_2 can be calculated as:

$$e^{-\lambda t_1} - e^{-\lambda t_2}$$

The probability of failure by time T= $[0, t_2]$ can be achieved by the following formula according to integral calculation rules:

$F(t) = \int_0^{t_2} f(t)dt = 1 - e^{-\lambda t_2}$ for continuous f(t)

$F(t) = \sum_{i=1}^{0} f(t_i)$ for discrete f(t)

According to (Laird and Brennan, 2006), the **Reliableness** function is the probability that a system does not fail by time t. Therefore, it is equal to one minus the probability it has failed by time *t*. That is:

$$R_t(A) = 1 - F(t)$$

Formulae for **Reliableness** calculation -developed in this thesis- and objective function are defined as follows:

E	$R_t(A) = 1 - F(t)$ $F(t) = \int_0^{t} f(t)dt = 1 - e^{-\lambda t}$ for continuous f(t) $F(t) = \sum_{i=1}^{0} f(t_i)$ for discrete f(t) $\lambda = 1/MTTF(A)$	$R_t(A)$ =Reliableness of activity by time t F(t)= probability of Failure during time interval of [0,t] f(t)= failure distribution function λ = the instantaneous failure rate MTTF(A)= Mean-Time-To-Failure of activity
E	OF: Max $(R_t(A))$	OF= Objective Function

Failure Frequency

Failure simply means an act of failing and **Activity Failure Frequency** indicates the number of failures occurred during an activity execution within a time unit, or percentage of failures within a certain number of instances (determined by stakeholders and expressed as percentage).

M	$ff_t(a) = \frac{n_f(a)}{t}$	$ff_t(a)$ = activity Failure frequency $n_f(a)$ = Number of instances of activity "a" that failed t = observation interval duration
E	$FF_t(a) = \frac{N_f(A)}{t}$	$FF_t(A)$ = activity Failure frequency $N_f(A)$ = (estimated) Number of instances of activity "a" that failed t = interval duration
M	of: Min [ff(a)]	of= Objective Function
M	$ff(a) = \frac{n_f(a)}{n(a)} \times 100$	ff(a) = activity Failure frequency $n_f(a)$ =Number of instances of activity that failed within a certain number of instances $n(a)$ =Total number of instances of activity
E	$FF(A) = \frac{N_f(A)}{N(A)} \times 100$	FF(A) = activity Failure frequency $N_f(A)$ =(estimated) Number of instances of activity that failed within a certain number of instances $N(A)$ =Total number of instances of activity
E	OF: Min [FF(A)]	OF= Objective Function

4.3.5. Permissibility

Permissibility is defined as the official permission, or approval, to perform a task or use a resource. **Authority** is a quality factor identified under the **Permissibility** quality dimension.

Authority

Authority is defined as an official permission or approval. This quality factor is defined for input and activity concept. **Activity Authority** is defined as the permission of specific swim-lanes (actors) to execute an activity. Different weights can be specified to different actors violating **Authority** of an activity. A weight has a direct relationship with the severity of the harm caused by violating the **Authority**. Measuring weights is not a

4

straightforward task and $\mathbf{w_k}$ can be determined through implementing different techniques ((Saaty, 1980, Leskinen, 2000, Mon et al.)).

It is assumed that a single actor performs the activity. Thus, for estimation of authority, probabilities of execution by all possible actors are incorporated including the authorised one. Formulae for **Authority** calculation and objective function -introduced in this thesis- are defined as follows:

M	$u(a) = \{1 - \sum_{k=1}^{n}[w_k \times uv_k\,(a)]\} \times 100$ $uv_K\,(a) = 1$ if activity "a" is performed by unauthorised actor "k" $uv_K\,(a) = 0$ if activity "a" is performed by authorised actor "k" $\sum_{k=1}^{n} uv_k(a) \leq 1$ $w_k \leq 1$	$u(a)$ = aUthority measurement of an activity $uv_k(a)$ = activity aUthority Violence by actor "k" w_k= Weight of actor "k" n= number of actors
M	OF: u(a) = 100%	OF= Objective Function
E	$U(A) = \{1 - \sum_{k=1}^{n}[W_k \times P_k(A) \times UV_k\,(A)]\} \times 100$ $UV_K\,(A) = 1$ if activity "A" is performed by unauthorised actor "K" $UV_K\,(A) = 0$ if activity "A" is performed by authorised actor "K" $\sum_{K=1}^{n} P_K(A) = 1$ $W_K \leq 1$	$U(A)$= aUthority of an Activity $UV_k(A)$ = Activity aUthority Violence by actor "k" W_K = Weight of actor "K" n = number of actors $P_k(A)$ =Probability of execution by actor "K"
E	OF: U(a) = 100%	OF= Objective Function

Input Authority indicates that an input (whether in the form of a piece of information or a raw material etc.) can be consumed by authorised activities. Therefore, the **Authority** of an input is violated by being used by a non-authorised activity. Different weights can be specified to different activities violating **Authority** of an input. A weight is expressed as percentage and has a direct relationship with the severity of the harm caused by violating usage of an input. For an input **Authority** computation, it is assumed that a single activity can use the input at a time. Thus, for estimation of authority, probabilities of utilisation by all possible activities are incorporated in the calculation including the authorised one.

Formulae for **Authority** calculation and objective function - introduced in this thesis- are defined as follows:

M	$u(i) = \{1 - \sum_{j=1}^{n} [w_j \times UV_j\,(i)]\} \times 100$ $uv_j(i) = 1$ if input "i" is used by unauthorised activity "j" $uv_j(i) = 0$ if input "i" is used by authorised activity "j" $\sum_{j=1}^{n} uv_j\,(i) \leq 1$ $w_j \leq 1$	$u(i)$ =aUthority measurement of an input $uv_j(i)$ = input aUthority Violence by activity " j" w_j= weight of activity "j" n= number of activities
M	of: u(i)= 100%	of= Objective Function
E	$U(I) = \{1 - \sum_{j=1}^{n} [W_j \times P_j(I) \times UV_j\,(I)]\} \times 100$ $UV_j(I) = 1$ if input "i" is used by unauthorised activity "j" $UV_j(I) = 0$ if input "i" is used by authorised activity "j" $\sum_{j=1}^{n} UV_j(I) \leq 1$ $W_j \leq 1$ $\sum_{j=1}^{n} P_j(I) = 1$	$U(I)$ = aUthority estimation of an input $UV_j(I)$ = input aUthority Violence by activity " j" W_j= weight of activity "j" n= number of activities $P_j(I)$ =Probability of utilisation of input i by activity "j"
E	OF: U(I)= 100%	OF= Objective Function

4.3.6. Availability

Availability is defined as a measure of readiness for usage for an input. Three quality factors of **Availableness, Time to Shortage** and **Time to Access** are categorised under this quality dimension.

Time to Access

There are times that an input is not available for a business process. When a shortage occurs, it is necessary to regain the input again so that the business process runs. The duration of the period a business process (or a part of it) cannot be executed until the input is regained, is called **Time to Access** of an input. The aim is to shorten this time as much as possible. The formula for calculation and the objective function are defined as follows:

M	$ta(i) = \sum_{k=1}^{n} tos_k(i)$	ta(i) = Time to Access of an input tos_k (i)= Time Of Shortage k of an input n=number of shortages
M	of: Min [ta(i)]	of= Objective Function
E	$TA(I) = \sum_{k=1}^{n} TOS_k(i)$	TA(I) = Time to Access of an input TOS_k (I)= Time Of Shortage k of an input n=number of shortages
E	OF: Min [TA(I)]	OF= Objective Function

Time to Shortage

There are times that an input is available for a business process to be used. There might be times that there is a shortage of an input. **Time to Shortage** is considered as a quality factor indicating the availability of an input. **Time to Shortage** for an input is defined as the duration that the input is available. The aim is to have **Time to Shortage** as long as possible. The formula for **Time to Shortage** calculation and its objective function -introduced in this thesis- are defined as follows:

M	$ts\ (i) = \sum_{k=1}^{n} at_k(i)$	ts(i)= Time to Shortage of input at_k(i)= Availability Time k of an input during an activity execution
M	of: Max [ts(i)]	of= Objective Function
E	$TS(I) = \sum_{k=1}^{n} AT_k(I)$	TS(I)= Time to Shortage of input AT_k(I)= (estimated) Availability Time k of an input during an activity execution
E	OF: Max [TS(I)]	OF= Objective Function

Availableness

Availableness is the percentage of time that a business process has access to its required input. The two elements that impact **Availableness** are: **Time to Shortage** and **Time to Access.** The aim is to increase this percentage. To improve **Availableness**, there is a need to increase the length of access and decrease the length of the shortage. The formula for the calculation and objective function -introduced in this thesis- are defined as follows:

M	$a(i) = \frac{ts(i)}{ts(i) + ta(i)} \times 100$	a(i)= Availableness of an input instance ts(i)= Time to Shortage of an input instance ta(i)= Time to Access of an input instance
M	of: Max a(i)	of= Objective Function
E	$A(I) = \frac{TS(I)}{TS(I) + TA(I)} \times 100$	A(I)= Availableness of an input instance TS(I)= Time to Shortage of an input instance TA(I)= Time to Access of an input instance
E	OF: Max A(I)	OF= Objective Function

4.4. Demonstration of Applicability for a Running Example

Instantiation can be considered as an experiment in the real world. Based on (Hevner et al., 2004), most of the behavioural research focuses on instantiation. Instantiations show that constructs, models, or methods can be implemented in a working system. They demonstrate feasibility, enabling concrete assessment of artefact suitability to its intended purpose. They also enable researchers to learn about the real world, how the artefact affects it, and how users appropriate it.

The running example is a simplified version of a real-world business process, namely "Accepting client" provided by Organisation C[1] (Figure 23).

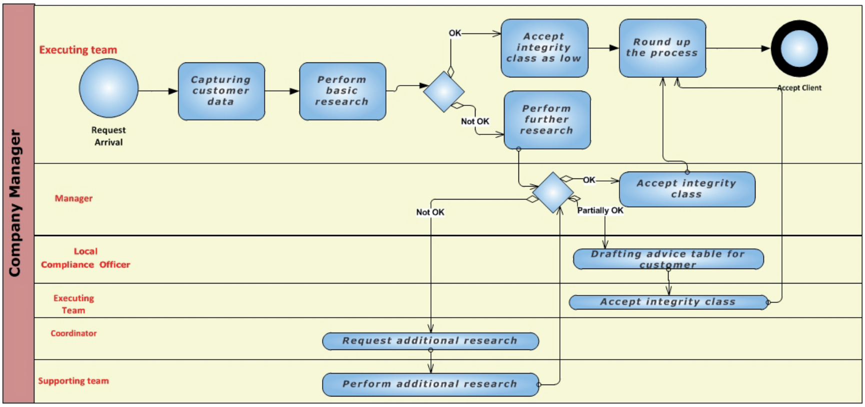

Figure 23 Running example

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1 International financial service provider

Figure 24 illustrates not only the business process in terms of a model, but it also provides examples of the related elements for quality specification and measurement considering the business process concepts. Later, the conceptual framework is instantiated (Figure 25) to demonstrate how its application relates to the example.

As can be observed from Figure 24, there are different departments/roles involved in this process. The process trigger is the arrival of a request to accept a client. To this end, a set of activities is performed in a predefined order. Some related quality factors are shown in Figure 24, namely uptime, downtime, maturity, authority, timeliness, cycle time, and throughput. Quality factors are assigned to the business process concepts via dashed lines as shown. For the purpose of distinction, quality factors are shown in a separate box below the example. The "business process" is presented by applying BPMN as a "Business process modelling language" supported by a business process ontology, e.g. (Heidari et al., 2011).

Figure 24 shows that the quality requirement of "Capturing client data should be executed more than 95% of the time without failure" is associated with the business processes concept of "Capturing client data"; this concept belongs to the business process of "Accepting client". The requirement is expressed by the "Company manager" as the stakeholder and is operationally queried by questions of "What is the percentage of the time that the execution is without failure out of the whole time of execution?" The quality factor "maturity" can be measured by a quality metric expressed as follows:

$$m(a)=\{upt(a)/[upt(a)+dot(a)\}*100$$

Where "a" denotes the "Activity", upt(a) is the "UPTime", and dot(a) is the "DownTime".

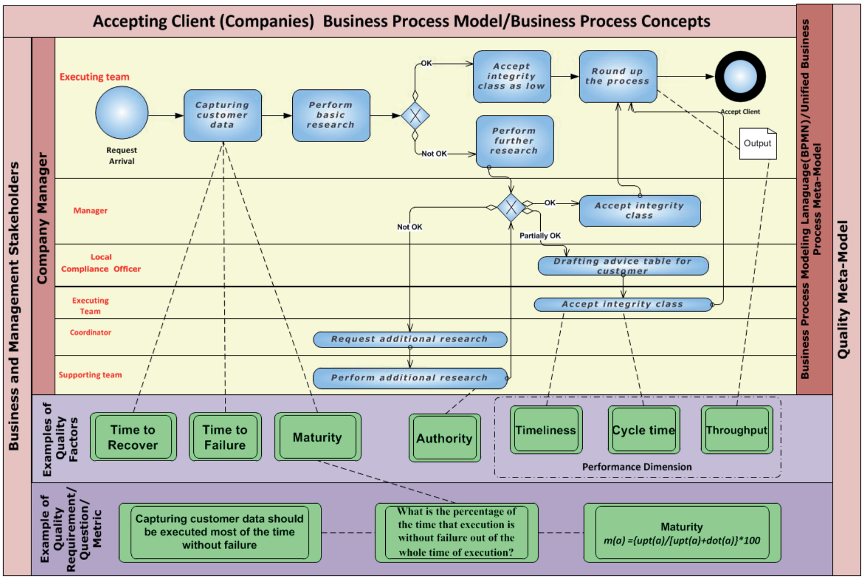


Figure 24 Accepting client business process and examples of quality factor, requirement, question and metric

Applicability of the proposed approach is also demonstrated by instantiation of the conceptual framework (Figure 25) with regard to the example. The instantiation focuses on the quality objective of “Capturing client data should be executed more than 95% of the time without failure.” Instances are introduced as “roles” in “fact tables”. Information in the fact tables is in line with the example described earlier and provided in Figure 24.

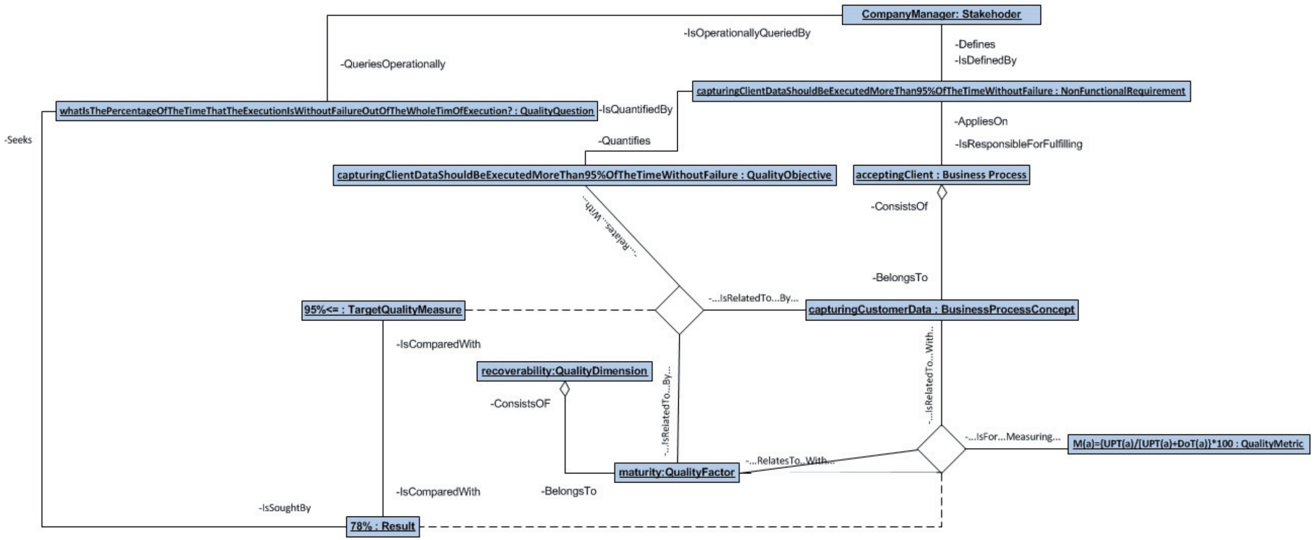


Figure 25 Conceptual framework instantiation for the process of accepting a client ("Capturing client data should be executed more than 95% of the time without failure.")

4.5. Conclusion and Future Work

This chapter provides an answer to the research question of "Can the quality of individual concepts of a business process be computed?" Using the same criteria as those for evaluating the existing approaches, the methodological stance of BPC-QC is systematic in that it considers specific concepts found in a business process modelling and subjects these to an analysis according to defined quality dimensions, detailed quality factors and metrics associated with them. In BPC-QC, stakeholders express quality goals, which may often be vague, but this vagueness is removed by analysing the soft goals into objectified components, quality objectives and quality questions which are specifically defined on quality factors for specific business process concepts. A set of phases is prescribed with details on the 'way of working' within each phase, that is, (a) focus of work, (b) required inputs, (c) expected outputs, (d) techniques used, and (e) support tools. On the basis of these four criteria, BPC-QC is systematic in that there is an identifiable and generic approach by focusing on quality requirements expressed by stakeholders (the focus), analysing these requirements in terms of the quality goals and questions (the input), deriving a quality measure (the output), using quantitative techniques for such a measure (the technique), and finally having a formal representation scheme for automated support (the tools).

Representation of business processes via a business process modelling language provides a formal expression of business processes; this fosters mutual understanding and comprehension of business processes between different stakeholders. Modelling in BPC-QC is *formal* because it supports at the very least some of the most popular BPMLs in practice, and these languages have their own formal definitions. In BPC-QC, a meta-model is developed that formally supports different language concepts upon which quality criteria may be established and measured. It is also *independent* of a specific language, which makes the potential use of BPC-QC much wider than if it were tied to a specific BPML. Measuring business processes in an objective manner is supported by the introduction of quantitative metrics. Thus, measuring of qualities in BPC-QC is formal in that the metrics used in BPC-QC do not allow for a subjective interpretation of the evaluation process. The quality framework, quality factors and metrics introduced in BPC-QC are not tied to a specific domain or application. Thus, the utility of BPC-QC is *generic*. For the granularity concept, the focus of this chapter is on measuring quality of business process concepts (i.e. low-level granularity).

According to these five evaluation criteria, BPC-QC meets its original objectives as stated in Chapter 1. BPC-QC provides a framework for modelling, analysing and reviewing business processes to answer the question of "Can one analyse the effectiveness of a business process?" To answer this question, the goals and quality requirements as articulated by different stakeholders need to be understood, and the degree a business process meets these requirements be evaluated. To this end, the research shows that:

- A quality evaluation approach can be adopted independent of a business process modelling language;
- Quality factors can be introduced specifically for the concepts of a business process;
- Quantitative metrics can be developed for specific quality factors, in such a way so as to compute different aspects of the quality of a business process.

On the basis of the results presented in this chapter, it is possible to identify a number of future extensions and developments both in theoretical and practical perspectives. Presently, there are six areas that are being investigated using the discussed approach as their baseline.

The first area is to extend the approach with dependencies on the selection of quality dimensions, factors and metrics. This area is concerned with the intertwining of such factors, and the analysis of such interdependencies is likely to yield a more holistic view of quality in business processes (Jarke et al., 2011). For example, there may be dependencies on the proposed quality measure (e.g., a slower execution time may infer a lower cost). Second, the results establishes a basis upon which different methodological and technological developments may emerge, such as an extension of existing business process modelling tools with a simulation component, the development of a workbench for analysing measured qualities, and the development of further cases on an industrial basis (Karagiannis, 2008). One direction for future research is to explore possibilities to enhance an existing industrial business process-modelling tool with quality evaluation extensions. The third area is to couple strategic modelling approaches such as system dynamics to business process modelling using parametric definitions according to quality criteria, and to experiment with 'what-if scenarios,' thus giving stakeholders an early view of the impact of their choices on the behaviour of a business process (Loucopoulos et al., 2003a). The fourth area is to consider a collaborative business process method as a valid extension to be able to deal with the issue of complex business processes. Handling these business processes demands collaboration and participation of different partners in modelling business processes (Barjis, 2009). The fifth area is to calculate requirement fulfilment of a business process or a part, based on the results of the calculation of its constructing concepts. The sixth area is process mining. Process mining techniques help organisations to discover and analyse business processes based on raw event data (van der Aalst and Dustdar, 2012). The factors and metrics can be formally defined, based on XES facilitating the modelling and computation. XES is a standard for event logs that provides a format for the interchange of event log data between tools for process mining, data mining, text mining, and statistical analysis (Günther and Verbeek, 2014).

In conclusion, the results of the chapter are twofold. First, the conceptual framework and the corresponding meta-model provide the methodological means for developers to consider quality aspects from vague and fuzzy expressions as business goals to concrete, objective, and measurable factors applicable on a variety of key business process concepts. Second, the formal aspects of the thesis provide a basis for the development of algorithms for the establishment of computational solutions and support tools to assist in evaluating the degree of quality against stated requirements.

Chapter 5. Business Process Quality Computation: BP-QC

The science of today
is the technology of tomorrow.
-Edward Teller

5

5.1. Introduction

During modelling of existing or future business processes, stakeholders specify, negotiate, and agree on requirements for enterprises and information systems supporting these enterprises. In general, a business process is composed of several activities, organised and executed to achieve specific business requirements, including business process quality requirements. This chapter provides an answer to the research question of "Can the quality of a (part of) business process be computed on the basis of the results of computing quality of its constituent concepts?" Given the quality values of constituent activities and the way these activities are organised, this chapter presents a methodology for computing the overall quality of a business process. This chapter addresses the aforementioned objective through (a) a conceptual framework and method steps, (b) a set of generic rules and structural patterns that apply to business process models, and (c) a set of computational formulae tailored to compute different quality factors.

The approach that this chapter presents is called Business Process Quality Computation (BP-QC). It assumes that a business process model is expressed in a business process modelling language (BPML), and through analysis it computes the quality of the business process in terms of different quality dimensions. (Heidari and Loucopoulos, 2013) introduce the quality dimensions of "Performance", "Efficiency", "Recoverability", "Availability", "Reliability" and "Permissibility." The BP-QC approach is designed to be generic and intended to deal with different types of quality dimension.

It is assumed that a business process model represents an agreed definition of a business process and that it is well formed. In other words, the model becomes the medium of the computation, while (1) the real values for measurement are captured from the executions of business process instances, and (2) probabilities and figured values are utilised for estimation purposes.

In BP-QC, the analysis is carried out at a higher level of abstraction than the semantics and syntax of the particular BPML being used. Analysis is based on the constituent activities of a business process that collectively achieve defined business process quality requirements. While quality evaluation of individual activities of a business process in the context of business process modelling is a major concern (i.e., (Heidari and Loucopoulos, 2013, Heidari et al., 2011)), systematic consideration and computation of the quality of a business process on the basis of its constituent activities is considered by few researchers (i.e., (Cardoso et al., 2004) in the area of workflow).

The aim of BP-QC is to measure and estimate the quality of a business process on the basis of the computation results of its constituent activities for a set of quality dimensions. BP-QC is based on the following assumptions:

- Using conceptual models of business processes as a basis for quality computation.
- Decomposing business process models into distinct parts on the basis of a set of predefined patterns.
- Having access to the quality values (estimated or measured) of the constituent activities of a business process.

The approach identifies abstract composition patterns representing six structural elements of a composition, based on the syntaxes of mainstream BPMLs: (1) sequential, (2) parallel with synchronisation, (3) exclusive, (4) inclusive, (5) simple loop, and (6) complex loop. The quality of each part is computed through a set of formulae for a given quality factor. The results of computing the quality of constituent parts are then aggregated to determine the quality of the overall business process. Applicability of the approach in a real-life setting is demonstrated via an illustrative example.

The chapter is structured as follows. Section 5.2 presents the approach, called BP-QC (Business Process Quality Computation). Section 5.3 elaborates on business process patterns and their reduction. Section 5.4 introduces the computational formulae. Section 5.5 illustrates the proposed approach by means of a real-life business process. Section 5.6 provides a number of observations, reflections, and suggestions for future work.

5.2. Business Process Compositional Quality Computation Framework: BP-CQCF

An overall perspective of the BP-QC approach is presented in this section in terms of both its methodology and ontology, using conceptual modelling as the means for these definitions. This is achieved by examining the basic assumption underpinning BP-QC, the concepts upon which BP-QC is based, and the process used for applying BP-QC.

The research objective is grounded on the assumption of being able to decompose a given complex business process model into distinct parts. Decomposing a business process into smaller parts enables its quality computation on the basis of the computation results of its constituent activities. This assumption raises the following questions:

1. What is the basis of the decomposition? And how can decomposition be achieved in a systematic, repeatable and generic way? (Decomposition)
2. How can the quality of each part be computed? (Computation)
3. How can the results of computation of the quality of each part be aggregated to compute the quality of the given business process as a whole? (Aggregation)

In this section, answers are provided for the aforementioned questions. The methodology consists of three main steps: (a) decomposition, (b) computation, and (c) aggregation.

5.2.1. Background

The realisation of reusable and generic structural patterns makes the decomposition more straightforward (Gschwind et al., 2008). In general, via patterns one can redesign and reuse compositional knowledge based systems (Brazier et al., 1996). Tran et al. define process patterns as constructs capturing reusable development activities, which serve as building blocks for constructing new processes (Tran et al., 2007). Higher degree business processes can be described as a combination of these patterns (Gschwind et al., 2008).

Different generic patterns are proposed in the literature. In (Polyvyanyy et al., 2008), four abstraction patterns are introduced: sequential, block, loop and dead end. (Sadiq and Orlowska, 2000) introduce sequence, fork, synchronisation, merge, and choice patterns. With the aim of prediction of quality values, (Cardoso et al., 2004) consider block-structured process models containing sequences, XOR blocks, AND blocks, and structured loops. The most prominent example of abstract patterns is probably the well-known set of workflow patterns for control flow (van der Aalst et al., 2000a). Van der Aalst et al. introduces a workflow pattern framework as a collection of generic and recurring constructs.

BP-QC includes six generic control-flow patterns: sequential, parallel with synchronisation, exclusive, inclusive, simple loop, and complex loop. This set represents basic structural elements of a composition, which are frequently used during business process modelling. The control- flow perspective is often the back-bone of process models (van der Aalst, 2013) and these patterns cover the basic control-flow patterns (van der Aalst et al., 2000a) as well as “structured loop” and “ multi choice” and “structured synchronising merge” to cover inclusive, simple and loop complex loop patterns. Each pattern encompasses a specific syntax reflecting relationships between its constituent activities (Heidari et al., 2011).

Structurally, every pattern can be replaced by one aggregating activity. The semantics of this new aggregating activity correspond to the semantics of the replaced pattern. In other words, the patterns describe structural transformations and also define how to derive properties of the new process activity from the original ones. Aggregating a business process into one single activity serves the purpose of computation on the basis of individual constructs. Details are discussed in Section 5.4.

(Polyvyanyy et al., 2009) introduces an approach for abstracting business process models to reduce the complexity and level of detail in the given models, on the basis of decomposition and aggregation without introducing generic patterns for recognition of the process parts. (Polyvyanyy et al., 2008) replaces each fragment of the given EPC model with a new fragment, which provides a generalised view of the substituted process fragment on the basis of a set of elementary abstractions (i.e., patterns). (Sadiq and Orlowska, 2000) applies a set of reduction rules to predefined patterns to identify structural conflicts in process models. (Vanhatalo et al., 2009) considers a workflow graph as a model for the control flow of a business process and offers an approach for decomposition of a workflow graph into a hierarchy of sub-workflows without introducing generic patterns. (Cardoso et al., 2004) proposes an approach for estimation of workflow properties, deploying a Stochastic Workflow Reduction (SWR) algorithm (Cardoso et al., 2002a) to replace the identified patterns with a single task. The BP-QC approach is inspired by the Stochastic Workflow Reduction (SWR) algorithm (Cardoso et al., 2002a).

As mentioned, the scope of BP-QC is control-flow patterns. Replacing each pattern with an equivalent activity changes the structure of the business process, and a new business process with a more succinct structure is replacing the original one (Cardoso et al., 2002a). The approach transforms the structure of a business process model in a stepwise fashion. Each time a reduction rule is applied, the business process structure changes. This enables the computational formulae to be applied iteratively to ultimately compute the quality of the whole business process. The quality value of the remaining atomic activity is the value of the quality of the whole given business process. The approach enables decomposition of a business process model into parts, with incoming and outgoing connecting flows linking them to the other parts. When a part is reduced to a single activity, the connecting flows remain in the new structure. Similar approaches are also considered in (Cardoso et al., 2002a, Cardoso et al., 2004, Vanhatalo et al., 2009, Sadiq and Orlowska, 2000, Polyvyanyy et al., 2008).

5.2.2. Conceptual Model

The conceptual model of BP-CQCF (Business Process Compositional Quality Computation Framework) is shown in Figure 26 and represented in Object Role Modelling (ORM) notation (Halpin, 1997). Role naming is deployed rather than association naming, as the former has proved to have many advantages over the latter in communicating such models (Nijssen and Halpin, 1989, Halpin, 2001).

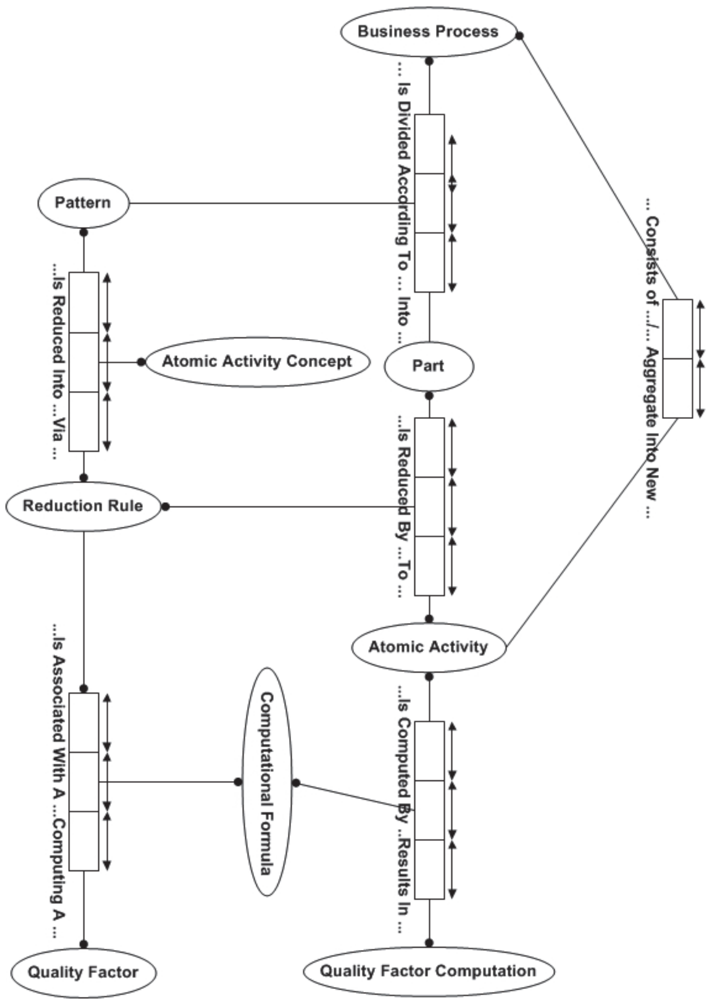


Figure 26 The BP-CQCF conceptual model

In BP-CQCF, a ***Business Process*** is divided into smaller ***Parts*** according to a set of predefined ***Patterns***. Each ***Pattern*** is reduced and converted into an ***Atomic Activity Concept*** according to a predefined ***Reduction Rule*** associated with the ***Pattern***. Consequently, each ***Part*** is reduced into an ***Atomic Activity***. Each ***Reduction Rule*** is associated with a ***Computational Formula*** measuring or estimating a ***Quality Factor***. Consequently, the quality of each resulting ***Atomic Activity*** is calculated by a ***Computational Formula***, leading to the desired ***Quality Computation***.

The resulting ***Atomic Activities*** are aggregated into a new ***Business Process*** and the reduction process can start again. Each time a reduction is applied, the business process's structure changes. The rules are repeatedly applied to the business process until only one atomic activity remains. This atomic activity represents the business process. Thus, the result of computation corresponding to the remaining atomic activity is the result of computation corresponding to the business process as a whole.

5

The conceptual model determines concepts used in BP-CQCF and guides the systematic application within the approach. Specifically, the approach is described as follows:

ALGORITHM .

```
BEGIN
    WHILE the business process is not a single atomic activity
        Decompose the business process into distinct parts based on the defined patterns;
        FOR each part
            Reduce it into a single atomic activity based on the reduction rules of its
          associated pattern;
            Compute the quality of the resulting activity via deploying a computational
          formula associated with the reduction rule and the desired quality factor;
        ENDFOR
        Aggregate the atomic activities resulting from the reductions into a new business
        process;
    ENDWHILE
    Record the result of the quality computation of the atomic activity as the quality of the
    business process;
END
```

5.3. Business Process Patterns

Workflow technology has emerged as an important tool for businesses to integrate and automate business processes. It is essential that business process models not only precisely capture business requirements, but also ensure successful workflow execution (Liu and Kumar, 2005). This section introduces the semantic equivalent of workflow patterns, specifically the control-flow patterns by (Russell et al., 2006) represented in CP-Nets. The six business process modelling patterns (BPMPs) are domain-independent modelling constructs, each of which organises its constituent elements in a unique way and is named after the syntactical category to which it belongs. This approach is not tied to a particular BPML and the symbols are deployed for the purpose of demonstration.

Patterns can be used to compose a well-structured business process model. In such a model, splits and joins are properly nested such that each split has a corresponding join of the same type (Laue and Mendling, 2010). (Lassen and van der Aalst, 2009) and (Laue and Mendling, 2010) use patterns and reduction to demonstrate the well-structuredness of workflows and business processes. Well-structuredness is a property requiring a strict block structuring of a process model (Dehnert and Zimmermann, 2005). Structured models can be built iteratively using the patterns as building blocks (Laue and Mendling, 2010). A well-structured business process model is well-behaving (Liu and Kumar, 2005), which allows to derive properties of the concerned business process.

This section formally defines the following patterns: sequential, parallel with synchronisation, exclusive, inclusive, simple loop and complex loop. Moreover, this section introduces the notion of well-structured business process part and patterns. Furthermore, the reduction of the patterns is defined formally.

In the remainder of this section, the following sets are used:

- Let A be a finite set of activities.
- Let G be a set of gateways.
- Let $G_{par\_with\_sync}, G_{excl}, G_{incl}, G_{simple\_loop}, G_{complex\_loop}$ be disjoint sets, such that their union is equal to G.
- Let $T_{AA} \subseteq A \times A$, $T_{AG} \subseteq A \times G$, $T_{GA} \subseteq G \times A$, and $T_{GG} \subseteq G \times G$ be disjoint sets of threads of control.

Any business process consists of at least one part. For all activities $a \in A$, the tuple $\langle a, \emptyset \rangle$ is a WSBPP (well-structured business process part).

a) Sequential: In this pattern, two or more business process parts are executed sequentially. If $a_1, a_2, \ldots, a_{n-1}, a_n$ are WSBPPs, then also $\langle \{ a_1, a_2, \ldots, a_{n-1}, a_n \}, \{(a_1, a_2), \ldots, (a_{n-1}, a_n)\} \rangle$ is a WSBPP. The result of reduction is an activity a_{S1n} (Figure 27).

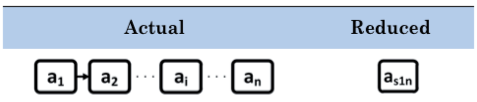


Figure 27 Business process modelling sequential pattern reduction.

This pattern is equivalent to sequence pattern (WCP-1), described as an activity in a sequence in a workflow that is enabled after completion of a preceding activity (Figure 28).

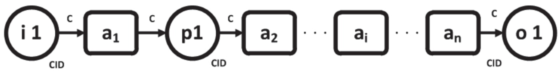


Figure 28 Sequential pattern (WCP-1) in a coloured Petri Net.

b) Parallel with synchronisation: In this pattern, multiple business process parts a_1, a_2, ..., a_n are executed concurrently and merged with synchronisation; that is, only after completion of all parts, the next part is initiated. If $g_a, g_b \in G_{par\_with\_sync}$ are gateways and $a_a, a_1, a_2, \dots, a_{n-1}, a_n, a_b$ are WSBPPs, then also $\langle\{\ a_a, a_1, a_2, \dots, a_{n-1}, a_n, a_b\ \}, \{(a_a, g_a), (g_a, a_1), (g_a, a_2), \dots, (g_a, a_n), (a_1, g_b), (a_2, g_b), \dots, (a_n, g_b), (g_b, a_b)\}\rangle$ is a WSBPP. The result of reduction is an activity a_{P1n} (Figure 29).

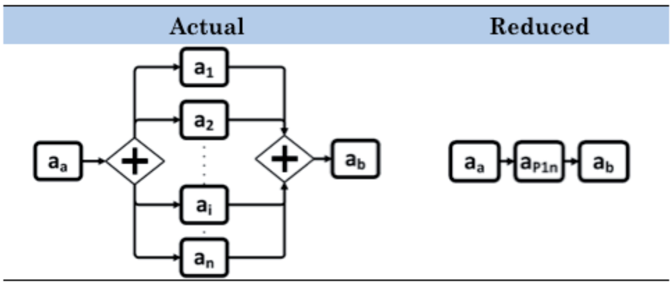


Figure 29 Business process modelling parallel with synchronisation pattern reduction.

This pattern is equivalent to the combination of parallel split (WCP-2) and synchronisation (WCP-3) patterns (Figure 30). Parallel split is the split of a branch into two or more parallel branches, each of which executes in parallel. Synchronisation is the join of two or more branches into a single subsequent branch when all input branches are enabled.

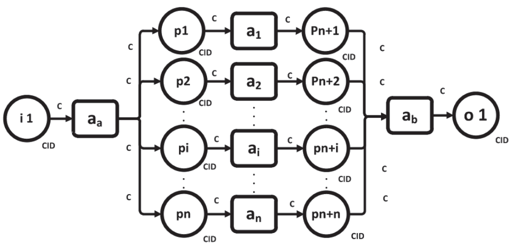


Figure 30 Combination of parallel split (WCP-2) and synchronisation patterns (WCP-3).

c) Exclusive: In this pattern, multiple business process parts $a_1, a_2, \ldots, a_n$ occur, of which only one can be executed. Execution of each part a_i is associated with a probability $p(a_i) > 0$, where $\sum_1^n p(a_i) = 1$. If $g_a, g_b \in G_{excl}$ are gateways and $a_a, a_1, a_2, \ldots, a_{n-1}, a_n, a_b$ are WSBPPs, then also $\langle\{ a_a, a_1, a_2, \ldots, a_{n-1}, a_n, a_b \}, \{(a_a, g_a), (g_a, a_1), (g_a, a_2), \ldots, (g_a, a_n), (a_1, g_b), (a_2, g_b), \ldots, (a_n, g_b), (g_b, a_b)\}\rangle$ is a WSBPP. The result of reduction is an activity a_{E1n} (Figure 31).

Actual	Reduced

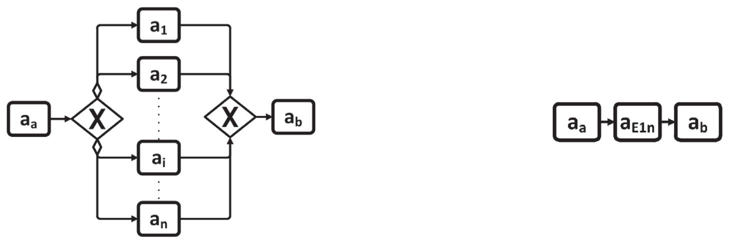


Figure 31 Business process modelling exclusive pattern reduction.

This pattern is equivalent to the combination of exclusive choice (WCP-4) and single merge (WCP-5) patterns (Figure 32). Exclusive choice is the split of a branch into two or more parallel branches, of which only one is passed by the thread of control based on the outcome of a logical expression associated with the branch. Single Merge is the join of two or more branches into a single subsequent branch where each enablement of an incoming branch results in the thread of control being passed to the subsequent branch.

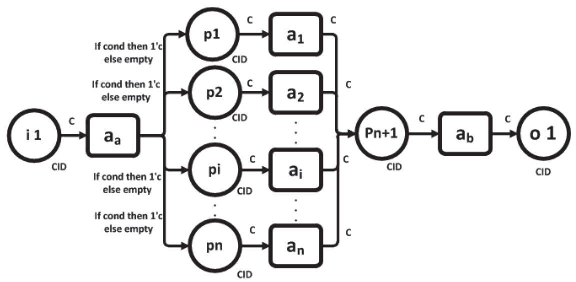


Figure 32 Combination of exclusive choice (WCP-4) and simple merge (WCP-5) patterns.

d) Inclusive: In this pattern, any combination of multiple business process parts a_1, a_2, ..., a_n, can be executed concurrently and merged with synchronisation. If $g_a, g_b \in G_{incl}$ are gateways and $a_a, a_1, a_2, \ldots, a_{n-1}, a_n, a_b$ are WSBPPs, then also $\langle\{ a_a, a_1, a_2, \ldots, a_{n-1}, a_n, a_b \}$,

$\{(a_a, g_a), (g_a, a_1), (g_a, a_2), \ldots, (g_a, a_n), (a_1, g_b), (a_2, g_b), \ldots, (a_n, g_b), (g_b, a_b)\}\rangle$ is a WSBPP. In this pattern, under certain conditions, business process parts are subdivided into a number of groups $g_1, g_2, \ldots, g_m$ and execution of each group is associated with a probability $p(g_k) > 0$, where $\sum_1^m p(g_k) = 1$. Groups can share activities with each other. The execution of one group indicates completion of the pattern. If $g_a, g_b \in G_{incl}$ are gateways, $a_a, a_1, a_2, \ldots, a_{n-1}, a_n, a_b$ are WSBPPs and $g_1, g_2, \ldots, g_m$ are sets of WSBPPs, such that their union equals $\{a_1, a_2, \ldots, a_{n-1}, a_n\}$, then $\langle\{\ a_a, a_1, a_2, \ldots, a_{n-1}, a_n, a_b\ \}$, $\{\ (a_a, g_a), (g_a, g_1), (g_a, g_2), \ldots, (g_a, g_m), (g_1, g_b), (g_2, g_b), \ldots, (g_m, g_b), (g_b, a_b)\ \}\rangle$ is a WSBPP. The result of reduction is an activity a_{I1n}. Figure 33 illustrates the initial structure of the pattern $a_1, a_2, \ldots, a_n$, a subdivision of business process parts into different groups $g_1, g_2, \ldots, g_m$, and the structure of the reduced activity.

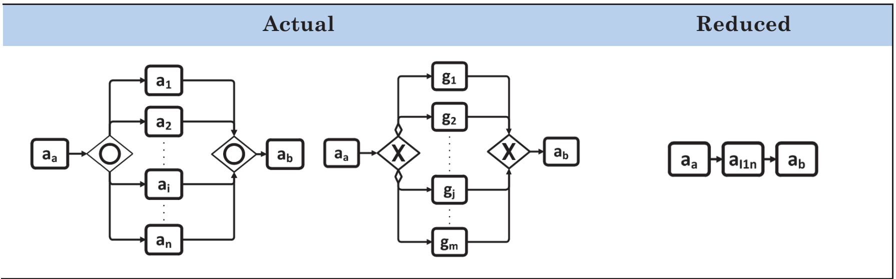


Figure 33 Business process modelling inclusive pattern reduction.

This pattern is equivalent to the combination of multi-choice (WCP-6) and synchronising merge (WCP-7) patterns (Figure 34). In the multi-choice pattern, the thread of control is passed to one or more of the outgoing branches. The structured synchronising merge pattern joins two or more branches into a single branch.

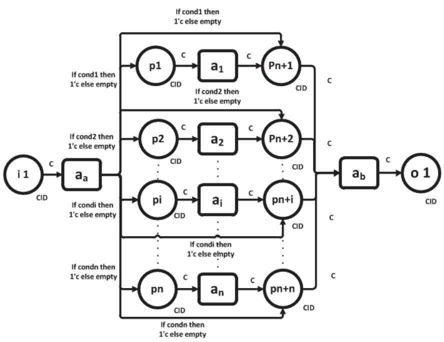
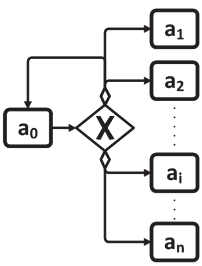
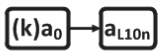
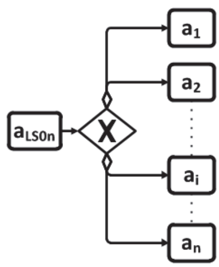


Figure 34 Combination of multi-choice (WCP-6) and structured synchronising merge (WCP-7) patterns.

e) Simple loop: The loop pattern is defined as a repetition of a business process part a_0 under a given condition, which precedes the gateway in the flow. After the gateway, one of multiple business process parts a_1, a_2, ..., a_n is executed, where $\sum_{i=0}^{n} p(a_i) = 1$. As with the exclusive pattern, knowledge of a priori probabilities of the parts in the cycle is necessary for effective estimation of quality. The loop can be expanded into a potentially infinite sequence (Zo et al., 2010).

If part a_0 is followed immediately by the gateway, then the loop is called a simple loop. Satisfaction of a condition determines whether or not to proceed to the next part. If $g \in G_{simple\_loop}$ is a gateway and $a_0, a_1, a_2, \dots, a_{n-1}, a_n$ are WSBPPs, then also $\langle \{a_0, a_1, a_2, \dots, a_{n-1}, a_n\}, \{(a_0, g), (g, a_0), (g, a_1), (g, a_2), \dots, (g, a_n)\} \rangle$ is a WSBPP. The result of reduction is an activity a_{LS0n}. In measurement, part a_0 can be repeated "k" times. In estimation, after reduction, new probabilities are associated with the parts, i.e. $p(a_{LSi})$, where $p(a_{LSri}) = \frac{p(a_i)}{1-p(a_0)}$, $\sum_{i=1}^{n} p(a_{LSi}) = 1$ (Figure 35).

f) Complex loop: A complex loop is a loop where multiple business process parts may be executed repeatedly, depending on the satisfaction of a condition. If $g \in G_{complex\_loop}$ is a gateway and $a_a, a_0, a_1, a_2, \dots, a_{n-1}, a_n$ are WSBPPs, then also $\langle \{ a_a, a_0, a_1, a_2, \dots, a_{n-1}, a_n \}, \{ (a_a, a_0), (a_0, g), (g, a_0), (g, a_1), (g, a_2), \dots, (g, a_n) \} \rangle$ is a WSBPP. The result of reduction is an activity a_{LC0n}. In measurement, part a_0 can be repeated "k" times. In estimation, after reduction, a set of new probabilities is associated with the parts, i.e. $p(a_{LCi})$, where $\sum_{i=1}^{n} p(a_{LCi}) = 1$.

Pattern	Actual	Reduced (Measurement)	Reduced (Estimation)
Simple Loop			

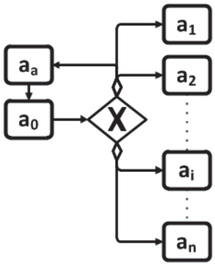
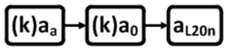
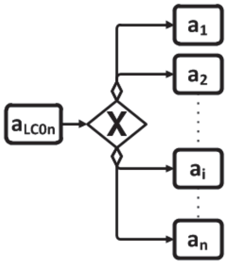
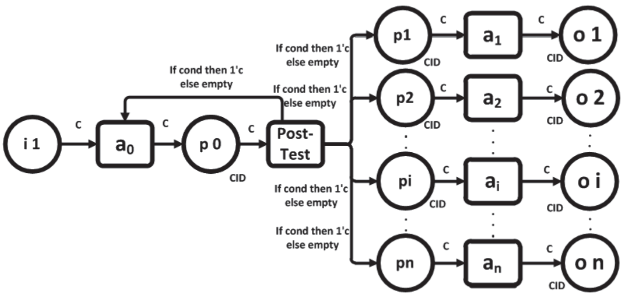
Pattern	Actual	Reduced (Measurement)	Reduced (Estimation)
Complex Loop			

Figure 35 Business process modelling loop pattern reduction.

A loop is semantically equivalent to the structured loop (WCP-21) pattern (Figure 36).

Simple loop



Complex loop

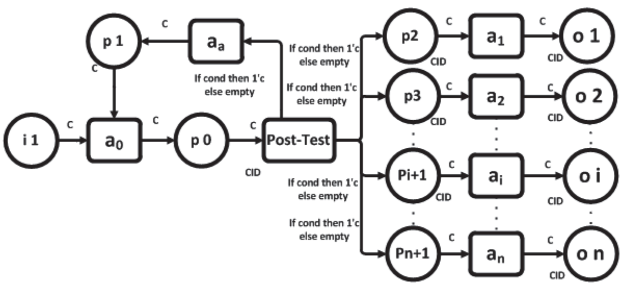


Figure 36 Structured loop pattern (WPC-21).

Table 9 provides a summary of the list of BPMPs (Business Process Modelling Patterns) and their semantically equivalent WCPs (Workflow Control-Flow patterns) with their reference number as defined by (Russell et al., 2006).

Table 9 BPMPs and their semantically equivalent WCPs.

No	BPMP	WCP
1	Sequential	Sequence (1)
2	Parallel with synchronisation	Parallel split (2) + synchronisation (3)
3	Exclusive	Exclusive choice (4) + simple merge (5)
4	Inclusive	Multi-choice (6) + structured synchronising merge (7)
5	Simple/complex loop	Structured loop (21)

The patterns are designed to provide a uniform, systematic, and generic approach for decomposition of business process models into parts and are used to model the structure of business process models. Most business processes can be specified using a relatively small subset of these patterns (Zo et al., 2010).

5.4. Computational Formulae

Each non-atomic business process can be subdivided into more manageable parts, using the patterns introduced in the previous section. This section describes how to compute the quality of the activity resulting from reducing a pattern. It is assumed that the quality value of each constituent activity of a pattern is independent of those of the others. For example, in a sequence pattern where activities are executed one after another, no matter how long an activity is going to take, the cycle times of its following activities will not be influenced. Furthermore, this thesis considers the normal execution of a business process, rather than an exceptional execution.

Figure 37 is derived from Figure 3 and depicts a positioning of business process quality computation in a model-driven architecture. As can be seen, estimation takes place at the model-level (business process type level) where the required data are estimated. At the runtime/data level (business process instance level), measurement takes place where required data are acquired through observation.

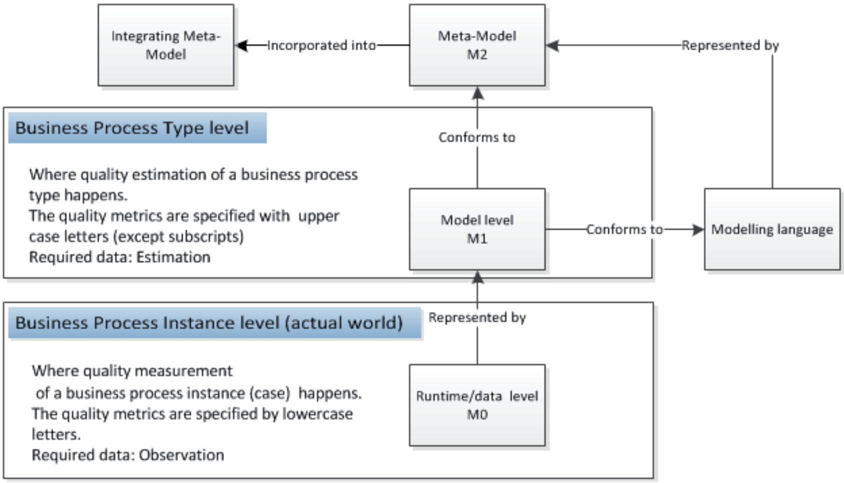


Figure 37 Positioning BP-QC in a model driven architecture

In the BP-QC approach, computational formulae for the quality dimensions of "Performance", "Recoverability", "Reliability", and "Permissibility" are introduced. The result of reducing a given pattern to an activity is denoted by "a" (for activity instances used in measurements) or "A" (for activity types used in estimations)[1], with a distinctive subscript corresponding to the pattern. For example, a_{S1n} indicates an activity instance that is the result of reducing a sequence flow S containing activity instances a_1 to a_n. The syntax of each pattern determines the computational formula.

Table 10 presents definitions of terms used throughout this chapter.

[1] Lowercase letters are utilised for formulating the measurement metrics and uppercase letters are utilised for formulating the estimation metrics

Table 10 Definitions of terms in BP-QC

Term	Definition (estimation)	Term	Definition (measurement)
A	Activity type	a	Activity instance
G	Group of activity types	g	Group of activity instances
$\mathbf{G}_k$	Group G_k of activity types	g_k	Group g_k of activity instances
$\mathbf{A}_{ki}$	Activity type A_i of group G_k	a_{ki}	Activity instance a_i of group g_k
$\mathbf{W}_i$ **	Weight of activity type A_i (for authority and maturity factors)	w_i **	Weight of activity instance a_i (for authority and maturity factors)
$\mathbf{V}_k$	Number of activity types in group G_k	v_k	Number of activity instances in group g_k
M	Number of activity type groups distinguished in a pattern	m	Number of activity instance groups distinguished in a pattern
$P(\boldsymbol{A})$ *	Probability of activity type A	---	-----
$P(\boldsymbol{G})$ *	Probability of activity type group G	---	-----

* In case of incorporation of several probabilities in a computation formula, it is assumed that their variances are equal.

** As the two factors of authority and maturity are expressed as a percentage, a normalisation should be considered when aggregating the values of multiple activities. Thus, different weights (w_i) are allocated to different activities (a_i) indicating their importance in the business process, while $\sum_{i=1}^{n} w_i = 1$ (n=number of whole activities in the business process). As mentioned earlier, measuring weights is no straightforward task, and w_i can be determined through implementing different techniques (Saaty, 1980, Leskinen, 2000, Mon et al.). Each activity in “sequence” and “parallel” patterns has its own quality value. All activities in an exclusive pattern and all activities after a gateway in a “loop” pattern are assigned the same weight value; in other words, the effect of the quality value for each choice is the same. In a “loop” pattern -for ease of calculation- the values of the repeating activities are only considered once. For every inclusive pattern, all groups of activities have the same value of quality and within each group different weights can be assigned to its constituent activities. The value of each constituent activity of the pattern is assumed to be independent of those of the others. For example, in a sequence pattern where activities are executed one after another, no matter what is the quality of an activity, the quality value of its following activities will not be influenced.

5.4.1. Sequential Pattern

This section describes formulae to compute the quality dimensions for a sequential pattern.

Performance

For the performance dimension, three factors of cycle time, timeliness, and cost are defined. The following describes the computational formulae for each factor.

- **Cycle time**

In both measurement and estimation, the cycle time of the resulting activity is equal to the sum of the cycle times of the reduced activities.

E[1]	$T(A_{S1n}) = \sum_{i=1}^{n} T(A_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $T(A)$ = Cycle time of activity A
M[2]	$t(a_{S1n}) = \sum_{i=1}^{n} t(a_i)$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n $t(a)$ = Cycle time of activity a

- **Timeliness**

In both measurement and estimation, the timeliness of the activity resulting from the reduction is equal to the sum of the timeliness values of the reduced activities.

E	$TI(A_{S1n}) = \sum_{i=1}^{n} TI(A_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $TI(A)$ = Timeliness of activity A
M	$ti(a_{S1n}) = \sum_{i=1}^{n} ti(a_i)$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n $ti(a)$ = Timeliness of activity a

[1] "E" denotes estimation.

[2] "M" denotes measurement.

- **Cost**

In both measurement and estimation, the cost of the activity resulting from the reduction is equal to the sum of the costs of the reduced activities.

E	$C(A_{S1n}) = \sum_{i=1}^{n} C(A_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $C(A)$ = Cost of activity A
M	$c(a_{S1n}) = \sum_{i=1}^{n} c(a_i)$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n $c(a)$ = Cost of activity a

Recoverability

For the recoverability dimension, three factors of uptime, downtime, and maturity are defined. The following describes the computational formulae for each factor.

5

- **Uptime**

In both measurement and estimation, the uptime of the activity resulting from the reduction is equal to the sum of the uptime values of the reduced activities.

E	$UPT(A_{S1n}) = \sum_{i=1}^{n} UPT(A_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $UPT(A)$ = Uptime of activity A
M	$upt(a_{S1n}) = \sum_{i=1}^{n} upt(a_i)$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n $upt(a)$ = uptime of activity a

- **Downtime**

In both measurement and estimation, the DownTime of the activity resulting from the reduction is equal to the sum of the time-to-recover values of the reduced activities.

E	$DOT\ (a_{S1n}) = \sum_{i=1}^{n} DOT(a_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $DOT(A)$ = DownTime of activity A
M	$dot\ (a_{S1n}) = \sum_{i=1}^{n} dot(a_i)$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n $dot(a)$ = DownTime of activity a

- **Maturity**

In both measurement and estimation, the maturity of the activity resulting from the reduction is equal to the sum of the maturity values of the reduced activities.

E	$M(a_{S1n}) = \sum_{i=1}^{n}[W_i \times M(A_i)]$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n M(A) = Maturity of activity *A*
M	$m(a_{S1n}) = \sum_{i=1}^{n}[w_i \times m(a_i)]$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n m(a) = Maturity of activity *a*

Reliability

5

For the reliability dimension, two factors of reliableness and failure frequency are defined. The following describes the computational formulae for each factor.

- **Reliableness**

Reliableness is considered only for estimation as it is a prediction in essence. The reliableness by time *t* of the activity resulting from the reduction is equal to the product of the reliableness values by time *t* of the reduced activities.

E	$R_t(A_{S1n}) = \prod_{i=1}^{n} R_t(A_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $R_t(A, t)$ = Reliableness of activity *A* by time t

- **Failure Frequency**

Two metrics are defined for failure frequency at the concept level. One metric considers the number of failures within a time unit. Considering this metric, in both measurement and estimation, the failure frequency during time *t* of the activity resulting from the reduction is equal to the sum of the failure frequencies during time *t* of the reduced activities.

E	$FF_t(A_{S1n}) = \sum_{i=1}^{n} FF_t(A_i)$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n FF_t (*A*) = Failure frequency of activity *A* by time *t*
M	$ff_t(a_{S1n}) = \sum_{i=1}^{n} ff_t(a_i)$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n ff_t (*a*) = Failure frequency of activity *a* by time *t*

Another metric considers the percentage of failures within a certain number of executions (instances in case of measurement). Considering this metric, in both measurement and estimation, the failure frequency of the activity resulting from the reduction is equal to the average of the failure frequencies of the reduced activities.

E	$FF(A_{S1n}) = [\sum_{i=1}^{n} FF(A_i)]/n$	A_{S1n} = Activity resulting from reduction of a sequence of activities A_1 to A_n $FF(A)$ = Failure frequency of activity A
M	$ff(a_{S1n}) = [\sum_{i=1}^{n} ff(a_i)]/n$	a_{S1n} = Activity resulting from reduction of a sequence of activities a_1 to a_n $ff(a)$ = Failure frequency of activity a

Permissibility (Authority)

For the permissibility dimension, the factor of authority is defined. The following describes the computational formula for this factor. In both measurement and estimation, the authority of the activity resulting from reduction is equal to the sum of the weighted authorities of the reduced activities.

E	$U(A_{S1n}) = \sum_{1}^{n}[W_i \times U(A_i)]$	A_{S1n} = Activity resulting from reduction of sequence activities A_1 to A_n $U(A)$ = Authority of activity A
M	$u(a_{S1n}) = \sum_{1}^{n}[w_i \times u(a_i)]$	a_{S1n} = Activity resulting from reduction of sequence activities a_1 to a_n $u(a)$ = Authority of activity a

5.4.2. Parallel with Synchronisation Pattern

This section describes formulae to compute the quality dimensions for a parallel-with-synchronisation pattern.

Performance

For the performance dimension, three factors of cycle time, timeliness, and cost are defined. The following describes the computational formulae for each factor.

Cycle time

In both measurement and estimation, the cycle time of the activity resulting from the reduction is equal to the maximum of the cycle times of the reduced activities.

E	$T(A_{P1n}) = Max_{i\in(1,\dots,n)} \{T(A_i)\}$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n T(A) = Cycle time of activity *A*
M	$t(a_{P1n}) = Max_{i\in(1,\dots,n)} \{t(a_i)\}$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n t(a) = Cycle time of activity *a*

Timeliness

In both measurement and estimation, the timeliness of the activity resulting from the reduction is equal to the minimum of the timeliness of the reduced activities.

E	$TI(A_{P1n}) = Min_{i\in(1,\dots,n)} \{TI(A_i)\}$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n TI(*A*) = Timeliness of activity *A*
M	$ti(a_{P1n}) = Min_{i\in(1,\dots,n)} \{ti(a_i)\}$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n ti(*a*) = Timeliness of activity *a*

Cost

In both measurement and estimation, the cost of the activity resulting from the reduction is equal to the sum of the costs of the reduced activities.

E	$C(A_{P1n}) = \sum_{i=1}^{n} C(A_i)$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n C(*A*) = Cost of activity *A*
M	$c(a_{P1n}) = \sum_{i=1}^{n} c(a_i)$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n c(*a*) = Cost of activity *a*

Recoverability

For the recoverability dimension, three factors of UPTime, DownTime, and maturity are defined. The following describes the computational formulae for each factor.

- **Uptime**

In both measurement and estimation, the Uptime of the activity resulting from the reduction is equal to the minimum of the time-to-failure values of the reduced activities.

E	$UPT(A_{P1n}) = Max_{i\in(1,\dots,n)}\{UPT(A_i)\}$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n $UPT(A)$ = UPTime of activity A
M	$upt(a_{P1n}) = Max_{i\in(1,\dots,n)}\{upt(a_i)\}$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n $upt(a)$ = UPTime of activity a

- **DownTime**

In both measurement and estimation, the DownTime of the activity resulting from the reduction is equal to the maximum of the time-to-recover values of the reduced activities.

E	$DOT(A_{P1n}) = Max_{i\in(1,\dots,n)}\{DOT(A_i)\}$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n $DOT(A)$ = DownTime of activity A
M	$dot(a_{P1n}) = Max_{i\in(1,\dots,n)}\{dot(a_i)\}$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n $DoT(a)$ = DownTime of activity a

- **Maturity**

In both measurement and estimation, the maturity of the activity resulting from the reduction is equal to the minimum of the maturity values of the reduced activities.

E	$M(A_{P1n}) = \sum_{i=1}^{n}[W_i \times M(A_i)]$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n M(A) = Maturity of activity A
M	$m(a_{P1n}) = \sum_{i=1}^{n}[w_i \times m(a_i)]$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n m(a) = Maturity of activity a

Reliability

For the reliability dimension, two factors of reliableness and failure frequency are defined. The following describes the computational formulae for each factor.

5

- **Reliableness**

In estimation, the reliableness by time *t* of the activity resulting from the reduction is equal to the product of the reliableness values by time *t* of the reduced activities.

E	$R_t(A_{P1n}) = \prod_{i=1}^{n} R_t(A_i)$	A_{S1n} = Activity resulting from reduction of parallel activities A_1 to A_n $R_t(A)$ = Reliableness of activity A by time t

- **Failure Frequency**

Two metrics are defined for failure frequency at the concept level. For the metric considering the number of failures within a time unit, in both measurement and estimation, the failure frequency during time *t* of the activity resulting from the reduction is equal to the sum of the failure frequencies during time *t* of the reduced activities.

E	$FF_t(A_{P1n}) = \sum_{i=1}^{n} FF_t(A_i)$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n $FF_t(A)$ = Failure frequency of activity A
M	$ff_t(a_{P1n}) = \sum_{i=1}^{n} ff_t(a_i)$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n $ff_t(a)$ = Failure frequency of activity a

For the metric considering the percentage of failures within a certain number of executions (instances in case of measurement), in both measurement and estimation, the failure frequency of the activity resulting from the reduction is equal to the average of the failure frequencies of the reduced activities.

E	$FF(A_{P1n}) = [\sum_{i=1}^{n} FF(A_i)]/n$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n $FF(A)$ = Failure frequency of activity a
M	$ff(a_{P1n}) = [\sum_{i=1}^{n} ff(a_i)]/n$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n $ff(a)$ = Failure frequency of activity a

Permissibility (Authority)

In both measurement and estimation, the authority of the resulting activity is equal to the sum of the weighted authorities of the reduced activities.

E	$U(A_{P1n}) = \sum_{i=1}^{n}[W_i \times U(A_i)]$	A_{P1n} = Activity resulting from reduction of parallel activities A_1 to A_n $U(A)$ = Authority of activity A
M	$u(a_{P1n}) = \sum_{i=1}^{n}[w_i \times u(a_i)]$	a_{P1n} = Activity resulting from reduction of parallel activities a_1 to a_n $u(a)$ = Authority of activity a

5.4.3. Exclusive Pattern

This section describes formulae to compute the quality dimensions for an exclusive pattern.

Performance

For the performance dimension, three factors of cycle time, timeliness, and cost are defined. The following describes the computational formulae for each factor.

- **Cycle time**

Measurement: The cycle time of the activity resulting from the reduction is equal to the cycle time of the activity executed in reality.

M	$t(a_{E1n}) = t(a_i)$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) $t(a)$= Cycle time of activity a

Estimation: The cycle time of the activity resulting from the reduction is equal to the sum of the products of the cycle times of the reduced activities and their associated probabilities.

E	$T(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times T(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of activities in exclusive pattern (A_1 to A_n) $T(A)$ = Cycle time of activity A

- **Timeliness**

Measurement: The timeliness of the activity resulting from the reduction is equal to the timeliness of the activity executed in reality.

M	$ti(a_{E1n}) = ti(a_i)$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) $ti(a)$ = Timeliness of activity a

Estimation: The timeliness of the activity resulting from the reduction is equal to the sum of the products of the timeliness values of the reduced activities and their associated probabilities.

E	$TI(a_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times TI(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of activities in exclusive pattern (A_1 to A_n) $TI(A)$ = Timeliness of activity A

- **Cost**

Measurement: The cost of the activity resulting from the reduction is equal to the cost of the activity executed in reality.

M	$c(a_{E1n}) = c(a_i)$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) $c(a)$ = Cost of activity a

Estimation: The cost of the resulting activity is equal to the sum of the multiplications of the costs of the reduced activities and their associated probabilities.

E	$C(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times C(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (A_1 to A_n) $C(A)$ = Cost of activity A

Recoverability

For the recoverability dimension, three factors of Uptime, Downtime, and maturity are defined. The following describes the computational formulae for each factor.

- **Uptime**

Measurement: The uptime of the activity resulting from the reduction is equal to the uptime of the activity executed in reality.

M	$upt(a_{E1n}) = upt(a_i)$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) $upt(a)$ = UPTime of activity a

Estimation: The Uptime of the activity resulting from the reduction is equal to the sum of the products of the time-to-failure values of the reduced activities and their associated probabilities.

E	$UPT(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times UPT(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of the activities in exclusive pattern (A_1 to A_n) UPT(A) = Uptime of activity A

- **Downtime**

Measurement: The Downtime of the activity resulting from the reduction is equal to the DownTime of the activity executed in reality.

M	$dot(a_{E1n}) = dot(a_i)$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) dot(a) = DownTime of activity a

Estimation: The uptime of the activity resulting from the reduction is equal to the sum of the products of the time-to-failure values of the reduced activities and their associated probabilities.

E	$DOT\ (A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times DOT(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (A_1 to A_n) DOT (A) = DownTime of activity A

- **Maturity**

Measurement: The maturity of the activity resulting from the reduction is equal to the maturity of the activity executed in reality multiplied by the weight associated to the pattern.

M	$m(a_{E1n}) = w_{aE1n} \times m(a_i)$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) m(a)= Maturity of activity a

Estimation: The maturity value of the activity resulting from the reduction is equal to the sum of the products of the maturity values of the reduced activities and their associated probabilities.

E	$M(A_{E1n}) = W_{AE1n} \times \sum_{i=1}^{n}[P(A_i) \times M(A)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (A_1 to A_n) M(A) = Maturity of activity A

5

Reliability

For the reliability dimension, two factors of reliableness and failure frequency are defined. The following describes the computational formulae for each factor.

- **Reliableness**

The estimated reliableness of the resulting activity by time *t* is equal to the sum of the multiplications of the reliableness values by time *t* of the reduced activities and their associated probabilities.

E	$R_t(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times R_t(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity from reduction of the activities in the exclusive pattern (A_1 to A_n) $R_t(A)$ = Reliableness of activity *A* by time *t*

A complete specification includes a distribution of likely values (Zo et al., 2010). Historical data provides relative frequencies, with probabilities summing up to 1. The reliableness metric represents a probability-weighted measure of the relative activity reliableness values.

- **Failure Frequency**

Measurement: Two metrics are defined for failure frequency at the concept level. For the metric considering the number of failures within a time unit, in both measurement and estimation, the failure frequency during time *t* of the activity resulting from the reduction is equal to the failure frequency during time *t* of the executed activity.

M	$ff_t(a_{E1n}) = ff_t(a_i)$	a_{E1n}= Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) $ff_t(a)$ = Failure frequency of activity *a*

For the metric considering the percentage of failures within a certain number of executions (instances in case of measurement), in both measurement and estimation, the failure frequency of the activity resulting from the reduction is equal to the failure frequency of the executed activity.

M	$ff(a_{E1n}) = ff(a_i)$	a_{P1n} = Activity resulting from reduction of exclusive activities a_1 to a_n $ff(a)$ = Failure frequency of activity *a*

Estimation: Two metrics are defined for failure frequency at the concept level. For the metric considering the number of failures within a time unit, in both measurement and estimation, the failure frequency during time *t* of the activity resulting from the reduction is equal to the sum of the products of the failure frequencies during time *t* of the reduced activities and their associated probabilities.

E	$FF_t\,(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times FF_t(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (A_1 to A_n) $FF_t\,(A)$ = Failure frequency of activity *A* during time *t*

For the metric considering the percentage of failures within a certain number of executions, the failure frequency of the activity resulting from the reduction is equal to the sum of the products of the failure frequencies of the reduced activities and their associated probabilities.

E	$FF(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times FF(A_i)]$ $\sum_{i=1}^{n} P(A_i) = 1$	A_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (A_1 to A_n) $FF(A)$ = Failure frequency of activity *A*

5

Permissibility (Authority)

For the permissibility dimension, the factor of authority is defined. The following describes the computational formula for this factor.

Measurement: The authority of the activity resulting from the reduction is equal to the product of the authority of the executed activity and its authority weight.

M	$u(a_{E1n}) = [w_i \times u(a_i)]$	a_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (a_1 to a_n) $u(a)$= Authority of activity a

Estimation: The authority of the resulting activity is equal to the sum of the multiplications of the authorities of the reduced activities and their associated probabilities.

E	$U(A_{E1n}) = \sum_{i=1}^{n}[P(A_i) \times W_i \times U(A_i)]$	A_{E1n} = Activity resulting from reduction of the activities in the exclusive pattern (A_1 to A_n) $U(A)$= Authority of activity A

A complete specification includes a distribution of likely values (Zo et al., 2010). Historical data provides relative frequencies, with probabilities summing up to 1. The authority metric represents a probability-weighted measure of the relative activity authority.

5.4.4. Inclusive Pattern

This section describes formulae to compute the quality dimensions for an inclusive pattern.

Performance

For the performance dimension, three factors of cycle time, timeliness, and cost are defined. The following describes the computational formulae for each factor.

- **Cycle time**

Measurement: The cycle time of the activity resulting from the reduction is equal to the maximum of the cycle times of the activities belonging to the executed group of activities.

M	$t(g_k) = Max_{i\in(1,\ldots,v_k)}\{t(a_{ki})\}$ $t(a_{I1n}) = t(g_k)$	a_{I1n}= Resulting activity from reduction of the activities in the inclusive pattern ($a_1$to a_n) $t(a)$= Cycle time of activity a

5

Estimation: The cycle time of a group is equal to the maximum of the cycle times of its constituent activities. The cycle time of the activity resulting from the reduction is equal to the sum of the products of the cycle times of all groups and their associated probabilities.

E	$T(G_k) = Max_{i\in(1,\ldots,v_k)}\{T(A_{ki})\}$ $T(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times T(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n}= Resulting activity from reduction of the activities in the inclusive pattern ($A_1$to A_n) $T(G)$= Cycle time of group G $T(A)$= Cycle time of activity A

- **Timeliness**

Measurement: The timeliness of the activity resulting from the reduction is equal to the minimum of the timeliness of the activities belonging to the executed group of activities.

M	$ti(g_k) = Min_{i\in(1,\ldots,v_k)}\{ti(a_{ki})\}$ $ti(a_{I1n}) = ti(g_k)$	a_{I1n}= Resulting activity from reduction of the activities in the inclusive pattern ($a_1$to a_n) $ti(a)$ = Timeliness of activity a $ti(g)$ = Timeliness of group g

Estimation: The timeliness of a group is equal to the minimum timeliness of its constituent activities. The timeliness of the activity resulting from the reduction is equal to the sum of the products of the timeliness of all groups and their associated probabilities.

E	$TI(G_k) = Min_{i\in(1,\ldots,v_k)}\{Ti(A_{ki})\}$ $TI(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times TI(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n}= Resulting activity from reduction of the activities in the inclusive pattern ($A_1$to A_n) TI(G)= Timeliness of group G TI(A)= Timeliness of activity *A*

- **Cost**

Measurement: The cost of the activity resulting from the reduction is equal to the sum of the costs of the activities belonging to the executed group of activities.

M	$c(g_k) = \sum_{i=1}^{v_k} c(a_{ki})$ $c(a_{I1n}) = c(g_k)$	a_{I1n}= Resulting activity from reduction of the activities in the inclusive pattern ($a_1$to a_n) $c(a)$ = Cost of activity a $c(g)$ = Cost of group g

Estimation: The cost of a group is equal to the sum of the cost of its constituent activities. The cost of the activity resulting from the reduction is equal to the sum of the products of the costs of all groups and their associated probabilities.

E	$C(G_k) = \sum_{i=1}^{v_k} C(A_{ki})$ $C(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times C(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n}= Resulting activity from reduction of the activities in the inclusive pattern ($A_1$to A_n) $C(A_{I1n})$= Cost of the resulting activity C(G)= Cost of group G C(*A*)= Cost of activity A

Recoverability

For the recoverability dimension, three factors of uptime, downtime, and maturity are defined. The following describes the computational formulae for each factor.

- **Uptime**

Measurement: The uptime of the activity resulting from the reduction is equal to the minimum of the time-to-recover values of the activities belonging to the executed group.

M	$upt(g_k) = Min_{i\in(1,\ldots,v_k)} \{upt(a_{ki})\}$ $upt(a_{I1n}) = upt(g_k)$	a_{I1n} = Activity resulting from reduction of inclusive activities $a_1$to a_n $upt(a)$ = uptime of activity a $upt(g)$ = uptime of group g

Estimation: The uptime of the activity resulting from the reduction is the sum of the products of the time-to-failure values of all groups and their associated probabilities.

E	$UPT(G_k) = Min_{i\in(1,\ldots,v_k)} \{UPT(A_{ki})\}$ $UPT(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times UPT(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n}= Activity resulting from reduction of inclusive activities A_1 to A_n $UPT(A)$ = UPTime of activity A $UPT(G)$ = UPTime of group G

- **Downtime**

Measurement: The Downtime of the activity resulting from the reduction is the maximum of the time-to-recover values of the activities belonging to the executed group of activities.

M	$dot(g_k) = Max_{i\in(1,\ldots,v_k)} \{dot(a_{ki})\}$ $dot(a_{I1n}) = dot(g_k)$	a_{I1n} = Activity resulting from reduction of inclusive activities a_1 to a_n $dot(a)$ = DownTime of activity a $dot(g)$ = DownTime of group g

Estimation: The Downtime of the activity resulting from the reduction is the sum of the products of the time-to-recover values of all groups and their associated probabilities.

E	$DOT(G_k) = Max_{i\in(1,\ldots,v_k)} \{DOT(A_{ki})\}$ $DOT(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times DOT(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n} = Resulting activity from reduction of inclusive activities A_1 to A_n $DOT(A)$ = DownTime of activity A $DOT(G)$ = DownTime of group G

- **Maturity**

Measurement: The maturity of the activity resulting from the reduction is equal to the minimum of the maturity values of the executed group of activities.

M	$m(g_k) = \sum_{i=1}^{v_k}[w_{ki} \times m(a_{ki})]$ $m(a_{I1n}) = m(g_k)$	a_{I1n} = Activity resulting from reduction of inclusive activities a_1 to a_n $m(a)$ = Maturity of activity a $m(g)$ = Maturity of group g

Estimation: The maturity of a group is equal to the minimum maturity of its constituent activities. The maturity of the activity resulting from the reduction is equal to the sum of the products of the maturity values of all groups and their associated probabilities.

E	$M(G_k) = \sum_{i=1}^{V_k}[W_{ki} \times M(A_{ki})]$ $M(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times M(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n} = Activity resulting from reduction of inclusive activities A_1 to A_n $M(A)$ = Maturity of activity A $M(G)$ = Maturity of group G

Reliability

For the reliability dimension, two factors of reliableness and failure frequency are defined. The following describes the computational formulae for each factor.

- **Reliableness**

Estimation: The reliableness of a group by time *t* is equal to the product of the reliableness values of its constituent activities by time *t*. The reliableness by time *t* of the activity resulting from the reduction is equal to the sum of the products of the reliableness values by time *t* of all groups and their associated probabilities.

E	$R_t(G_k) = \prod_{i=1}^{V_k} R_t(A_{ki})$ $R_t(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times R_t(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n} = Activity resulting from reduction of inclusive activities A_1 to A_n $R_t(A)$ = Reliableness of activity a by time t $R_t(G)$ = Reliableness of group g by time t

- **Failure Frequency**

Measurement: Two metrics are defined for failure frequency at the concept level. One metric considers the number of failures within a time unit. In this case, the failure frequency during time *t* of the activity resulting from the reduction is equal to the sum of the failure frequencies during time *t* of the executed group of activities.

M	$ff_t(g_k) = \sum_{i=1}^{V_k} ff_t(a_{ki})$ $ff_t(a_{I1n}) = ff_t(g_k)$	a_{I1n} = Activity resulting from reduction of the inclusive activities a_1 to a_n $ff_t(a)$ = Failure Frequency of activity a during time t $ff_t(g)$ = Failure Frequency of group g during time t

Another metric considers the percentage of failures within a certain number of instances. For this metric, the failure frequency of the activity resulting from the reduction is equal to the average of the failure frequencies of the executed group of activities.

M	$ff(g_k) = [\sum_{i=1}^{v_k} FF(a_{ki}) / v_k]$ $ff(a_{I1n}) = ff(g_k)$	a_{I1n} = Activity resulting from reduction of the inclusive activities a_1 to a_n ff(a) = Failure Frequency of activity a ff(g) = Failure Frequency of group g

Estimation: For the metric considering the number of failures within a time unit, the failure frequency during time *t* of a group is the sum of the failure frequencies during time *t* of its constituent activities. The failure frequency during time *t* of the activity resulting from the reduction is the sum of the products of the failure frequencies during time *t* of all groups and their associated probabilities.

E	$FF_t(G_k) = \sum_{i=1}^{V_k} FF_t(A_{ki})$ $FF_t(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times FF_t(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n} = Resulting activity from reduction of inclusive activities A_1 to A_n FF(A) = Failure Frequency of activity A FF(G) = Failure Frequency of group G

For the metric considering the percentage of failures within a certain number of executions, the failure frequency of a group is equal to the average of the failure frequencies of its constituent activities. The failure frequency of the activity resulting from the reduction is the sum of the products of the failure frequencies of all groups and their associated probabilities.

E	$FF(G_k) = [\sum_{i=1}^{V_k} FF(A_{ki})] / V_k$ $FF(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times FF(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n} = Resulting activity from reduction of inclusive activities A_1 to A_n FF(A) = Failure Frequency of activity A FF(G) = Failure Frequency of group G

Permissibility (Authority)

For the permissibility dimension, the factor of authority is defined. The following describes the computational formula for this factor.

Measurement: The authority of the activity resulting from the reduction is equal to the sum of the authority values of the executed group of activities and their authority weights.

M	$u(g_k) = \sum_{i=1}^{v_k}[w_{ki} \times u(a_{ki})]$ $u(a_{I1n}) = u(g_k)$	a_{I1n} = Activity resulting from reduction of inclusive activities a_1 to a_n $u(a)$ = Authority of activity a $u(g)$ = Authority of group g

Estimation: The authority of a group is equal to the sum of the authorities of its constituent activities. The authority of the activity resulting from the reduction is the sum of the products of the authority values of all groups and their associated probabilities.

E	$U(G_k) = \sum_{i=1}^{V_k}[W_{ki} \times U(A_{ki})]$ $U(A_{I1n}) = \sum_{k=1}^{m}[P(G_k) \times U(G_k)]$ $\sum_{k=1}^{m} P(G_k) = 1$	A_{I1n} = Activity resulting from reduction of the inclusive activities A_1 to A_n $U(A)$ = Authority of activity A $U(G)$ = Authority of group G

5

5.4.5. Loop Pattern

This section describes formulae to compute the quality dimensions for a loop pattern, in which some activities may be repeated several times before a certain condition is satisfied. As a result, the computation should incorporate the quality values of the repeated activity, or repeated activities, whether these values are measured or estimated.

For a simple loop, the possibly repeated activity is called activity 0, for short a_0. For a complex loop, whenever a_0 is repeated then another activity is executed immediately before a_0. This activity, for short a_a, is repeated the same number of times as a_0.

Repetition of an activity is mathematically equivalent to having it repeated in a sequence. With the exception of reliability factors, the computational formulae in this section apply to all quality factors distinguished in this thesis for activities in the approach to business process concept quality computation BPC-QC. This group of quality factors will be referred to as QF. The formulae were inspired by the work of (Cardoso et al., 2004, Zheng et al., 2009, Zo et al., 2010, Tsironis et al., 2010, Chuang et al., 2002, Oliveira et al., 2012) on cycle time and cost aspects. For reliableness and failure frequency computation, two separate sets of formulae are introduced. For estimation of quality factors, it is assumed that the value of the quality factor is constant during all iterations.

- **QF Computation**

Measurement: For a simple loop, the value for quality factor *qf* of the activity resulting from the reduction is equal to the sum of the values for *qf* of a_0 in different instances of this activity.

M	$qf(\mathrm{a_{LS0n}}) = \sum_{j=1}^{z+1} qf_j(\mathrm{a_0})$	$\mathrm{a_0}$ = Activity 0 (after its first instance repeated z times) $\mathrm{a_{LS0n}}$ = Activity resulting from reduction of loop activity $\mathrm{a_0}$ $qf(a)$ = Value for quality factor *qf* of activity a $qf_j(a)$ = Value for quality factor *qf* of activity a in its j^{th} instance z = Number of repeated instances in the loop

For a complex loop, the value for quality factor *qf* of the activity resulting from the reduction is equal to the sum of the values for *qf* of $\mathrm{a_0}$ and those for *qf* of $\mathrm{a_a}$.

M	$qf(\mathrm{a_{LC0n}}) = qf_1(\mathrm{a_0}) + \sum_{j=1}^{z}[qf_{j+1}(\mathrm{a_0}) + qf_j(\mathrm{a_a})]$	$\mathrm{a_0}$ = Activity 0 (after its first instance repeated z times) $\mathrm{a_a}$ = Activity a preceding activity 0 in a loop iteration $\mathrm{a_{LC0n}}$ = Activity resulting from reduction of loop activities $\mathrm{a_0}$ and $\mathrm{a_a}$ $qf(a)$ = Value for quality factor *qf* of activity a $qf_j(a)$ = Value for quality factor *qf* of activity a in its j^{th} instance z = Number of repeated instances in the loop

Estimation: When reducing a loop pattern, $\mathrm{a_0}$ is substituted, and in case of a complex loop, the same applies to $\mathrm{A_a}$. As a result, the probabilities of all other activities that are not reduced are affected, as they have a larger probability to get executed after the reduction. After reduction, the probability of each non-reduced activity is equal to the probability of the same activity before reduction, divided by the difference of one (or, one hundred per cent) and the probability of $\mathrm{A_0}$. To exclude loops that will never end under any circumstances, the probability of $\mathrm{A_0}$ is taken to be less than one (or, one hundred per cent).

For a simple loop, the value for a quality factor *QF* of the activity resulting from the reduction is computed as follows.

E	$QF(\mathrm{A_{LS0n}}) = \frac{QF(\mathrm{A_0})}{1 - \mathrm{P(A_0)}}, \mathrm{P(A_0)} < 1$ $\mathrm{P}(\mathrm{A}_{\mathrm{LS}ri}) = \frac{\mathrm{P}(\mathrm{A}_i)}{1 - \mathrm{P(a_0)}}, \mathrm{P(A_0)} < 1$ $\sum_{i=1}^{n} \mathrm{P}(\mathrm{A}_{\mathrm{LS}ri}) = 1$	$\mathrm{A_0}$ = Activity 0 (after its first execution possibly repeated) $\mathrm{A_{LS0n}}$ = Activity resulting from reduction of loop activity $\mathrm{A_0}$ $\mathrm{A}_{\mathrm{LS}ri}$ = Non-reduced activity i after reduction of loop activity $\mathrm{A_0}$ $QF(A)$ = Value for quality factor *QF* of activity A n = Number of non-reduced activities in the loop pattern

For a complex loop, the value for a quality factor *QF* of the activity resulting from the reduction is computed as follows.

E	$QF(\mathrm{A_{LC0n}}) = \frac{QF(\mathrm{A_0}) + QF(\mathrm{A_a})}{1 - \mathrm{P(a_0)}} - QF(\mathrm{A_a})$, $\mathrm{P(a_0)} < 1$ $\mathrm{P(A_{LCr\mathit{i}})} = \frac{\mathrm{P}(\mathrm{A}_i)}{1 - \mathrm{P(A_0)}}, \mathrm{P(A_0)} < 1$ $\sum_{i=1}^{n} \mathrm{P(A_{LCr\mathit{i}})} = 1$	$\mathrm{A_0}$ = Activity 0 (after its first execution possibly repeated) $\mathrm{A_a}$ = Activity a preceding activity 0 in a loop iteration $\mathrm{A_{LC0n}}$ = Activity resulting from reduction of loop activities $\mathrm{A_0}$and $\mathrm{A_a}$ $\mathrm{A_{LCr\mathit{i}}}$ = Non-reduced activity *i* after reduction of loop activities $\mathrm{A_0}$and $\mathrm{A_a}$ $QF(A)$= Value for quality factor *QF* of activity *A* n = Number of non-reduced activities in the loop pattern

- **Reliableness Computation**

Estimation: To estimate the reliableness of an activity by time *t* resulting from the reduction of a loop, formulae are used which are based on those by *(Cardoso et al., 2002b)*. For a simple loop, the following formula is used.

E	$\mathrm{R}_t(\mathrm{a_{LS0n}}) = \frac{[1 - \mathrm{P(A_0)}] \times \mathrm{R}_t(\mathrm{A_0})}{1 - [\mathrm{P(A_0)} \times \mathrm{R}_t(\mathrm{A_0})]}$ $\mathrm{P(A_{LSr\mathit{i}})} = \frac{\mathrm{P}(\mathrm{A}_i)}{1 - \mathrm{P(A_0)}}, \mathrm{P(A_0)} < 1$ $\sum_{i=1}^{n} \mathrm{P(A_{LSr\mathit{i}})} = 1$	$\mathrm{A_0}$ = Activity 0 (after its first execution possibly repeated) $\mathrm{A_{LS0n}}$ = Activity resulting from reduction of loop activity $\mathrm{A_0}$ $\mathrm{A_{LSr\mathit{i}}}$ = Non-reduced activity *i* after reduction of loop activity $\mathrm{A_0}$ $\mathrm{R}_t(A)$ = Reliableness of activity *A* n = Number of non-reduced activities in the loop pattern

For a complex loop, the following formula is used.

E	$\mathrm{R}_t(\mathrm{A_{LC0n}}) = \frac{[1 - \mathrm{P(A_0)}] \times \mathrm{R}_t(\mathrm{A_0})}{1 - [\mathrm{P(A_0)} \times \mathrm{R}_t(\mathrm{A_0\ t}) \times \mathrm{R}_t(\mathrm{A}_a)]}$ $\mathrm{P(A_{LCr\mathit{i}})} = \frac{\mathrm{P}(\mathrm{A}_i)}{1 - \mathrm{P(A_0)}}, \mathrm{P(a_0)} < 1$ $\sum_{i=1}^{n} \mathrm{P(A_{LCr\mathit{i}})} = 1$	$\mathrm{A_0}$ = Activity 0 (after its first execution possibly repeated) $\mathrm{A_a}$ = Activity a succeeding activity 0 (and also possibly repeated) $\mathrm{A_{LC0n}}$ = Activity resulting from reduction of loop activities $\mathrm{A_0}$and $\mathrm{A_a}$ $\mathrm{A_{LCr\mathit{i}}}$ = Non-reduced activity *i* after reduction of loop activities $\mathrm{A_0}$and $\mathrm{A_a}$ $\mathrm{R}_t(A)$ = Reliableness of activity *A* n = Number of non-reduced activities in the loop pattern

- **Failure Frequency Computation**

Measurement of a simple loop: Two metrics are defined for failure frequency at the concept level. One metric considers the number of failures within a time unit. For this metric, the failure frequency during time *t* of the activity resulting from the reduction of a simple loop is equal to the sum of the failure frequency values during time *t* of a_0 in different instances of this activity.

M	$ff_t(a_{LS0n}) = \sum_{j=1}^{z+1} ff_{t,j}(a_0)$	a_0 = Activity 0 (after its first instance repeated z times) a_{LS0n} = Activity resulting from reduction of loop activity a_0 $ff_t(a)$ = Failure frequency during time *t* of activity *a* $ff_{t,j}(a)$ = Failure frequency of activity *a* during time *t* in its j^{th} instance z = Number of repeated instances in the loop

For the metric considering the percentage of failures within a certain number of instances, the failure frequency of the activity resulting from the reduction of a simple loop is equal to the average of the failure frequency values of a_0 in different instances of this activity.

M	$ff(a_{LS0n}) = [\sum_{j=1}^{z+1} ff_j(a_0)] / (z + 1)$	a_0 = Activity 0 (after its first instance repeated z times) a_{LS0n} = Activity resulting from reduction of loop activity a_0 $ff(a)$ = Failure frequency of activity *a* $ff_j(a)$ = Failure frequency of activity *a* in its j^{th} instance z = Number of repeated instances in the loop

Measurement of a complex loop: For the metric considering the number of failures within a time unit, the failure frequency during time *t* of the activity resulting from the reduction of a complex loop is equal to the sum of the failure frequency values during time *t* of a_0 and those during time *t* of a_a.

M	$ff_t(a_{LC0n}) = ff_{t,1}(a_0) + \sum_{j=1}^{z}[ff_{t,j+1}(a_0) + ff_{t,j}(a_a)]$	a_0 = Activity 0 (after its first instance repeated z times) a_a = Activity a preceding activity 0 in a loop iteration a_{LC0n} = Activity resulting from reduction of loop activities a_0 and a_a $ff_t(a)$ = Failure frequency during time *t* of activity *a* $ff_{t,j}(a)$ = Failure frequency during time *t* of activity *a* in its j^{th} instance z = Number of repeated instances in the loop

For the metric considering the number of failures within a certain number of instances, the failure frequency of the activity resulting from the reduction of a complex loop is equal to the average of the failure frequency values of a_0 and those of a_a.

M	$ff(a_{LC0n}) = \frac{\left[\sum_{j=1}^{z+1} ff_j(a_0) + \sum_{j=1}^{z} ff_j(a_a)\right]}{2z+1}$	a_0 = Activity 0 (after its first instance repeated z times) a_a = Activity a preceding activity 0 (and also repeated z times) a_{LC0n} = Activity resulting from reduction of loop activities a_0 and a_a $ff(a)$ = Failure frequency of activity a $ff_j(a)$ = Failure frequency of activity a in its j^{th} instance z = Number of repeated instances in the loop

Estimation of a simple loop: For the metric considering the number of failures within a time unit, the failure frequency during time *t* of the activity resulting from the reduction of a simple loop is computed as follows:

E	$FF_t(A_{LS0n}) = \frac{FF_t(A_0)}{1 - P(A_0)}, P(A_0) < 1$ $P(A_{LSri}) = \frac{P(A_i)}{1 - P(A_0)}, P(A_0) < 1$ $\sum_{i=1}^{n} P(A_{LSri}) = 1$	A_0 = Activity 0 (after its first execution possibly repeated) A_{LS0n} = Activity resulting from reduction of loop activity A_0 A_{LSri} = Non-reduced activity *i* after reduction of loop activity A_0 $FF_t(A)$ = Failure frequency during time *t* of activity *A* n = Number of non-reduced activities in the loop pattern

For the metric considering the percentage of failures within a certain number of executions, the failure frequency of the activity resulting from the reduction of a simple loop is computed as follows:

E	$FF(A_{LS0n}) = \frac{FF(A_0)}{1 - P(A_0)}, P(A_0) < 1$ $P(A_{LSri}) = \frac{P(A_i)}{1 - P(A_0)}, P(A_0) < 1$ $\sum_{i=1}^{n} P(A_{LSri}) = 1$	A_0 = Activity 0 (after its first execution possibly repeated) A_{LS0n} = Activity resulting from reduction of loop activity A_0 A_{LSri} = Non-reduced activity *i* after reduction of loop activity A_0 $FF(A)$ = Failure frequency of activity *A* n = Number of non-reduced activities in the loop pattern

Estimation of a complex loop: For the metric considering the number of failures within a time unit, the failure frequency of the activity resulting from the reduction of a complex loop is computed as follows:

E	$FF_t(A_{LC0n}) = \frac{FF_t(A_0) + FF_t(A_a)}{1 - P(a_0)} - FF_t(A_a), P(A) < 1$ $P(A_{LCri}) = \frac{P(A_i)}{1 - P(A_0)}, P(A_0) < 1$ $\sum_{i=1}^{n} P(A_{LCri}) = 1$	A_0 = Activity 0 (after its first execution possibly repeated) A_a = Activity A preceding activity 0 in a loop iteration A_{LC0n} = Activity resulting from reduction of loop activities A_0 and A_a A_{LCri} = Non-reduced activity *i* after reduction of loop activities A_0 and A_a $FF_t(A)$ = Failure frequency during time *t* of activity *A* n = Number of non-reduced activities in the loop pattern

For the metric considering the percentages of failures within a certain number of executions, the failure frequency of the activity resulting from the reduction of a complex loop is computed as follows:

E	$FF(A_{LC0n}) = \frac{FF(A_0) + FF(A_a)}{2 \times [1 - p(A_0)]} - FF(A_a), P(A_0) < 1$ $P(A_{LCri}) = \frac{P(A_i)}{1 - P(A_0)}, P(A_0) < 1$ $\sum_{i=1}^{n} P(A_{LCri}) = 1$	A_0 = Activity 0 (after its first execution possibly repeated) A_a = Activity a succeeding activity 0 (and also possibly repeated) A_{LC0n} = Activity resulting from reduction of loop activities A_0 and A_a A_{LCri} = Non-reduced activity *i* after reduction of loop activities A_0 and A_a FF(*A*) = Failure frequency of activity *A* n = Number of non-reduced activities in the loop pattern

5.5. Demonstration of Applicability for the Running Example

The applicability of the approach is demonstrated for the running example, namely “Accepting Client” from Organisation C. Figure 38 illustrates the business process, using BPMN as a business process modelling language. As can be observed from Figure 38, there are different departments/roles involved in the process. The process trigger is the arrival of a request to accept a client. When the process is running, a set of activities is performed in a predefined order.

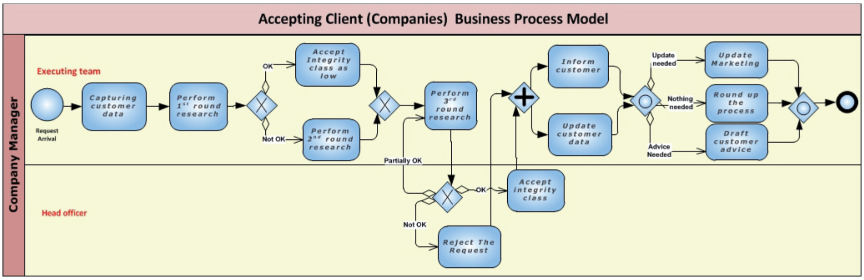


Figure 38 Accepting client business process

The business process's requirements include the following: "The outcome should be delivered within 16 weeks, as specified by the company manager." This requirement defines a limit for the cycle time of the business process.

Table 11 introduces the estimated/measured cycle time of each activity and their probabilities. A symbol for each activity is introduced for the ease of communication throughout the computation. One instantiation of the business process is generated for the purpose of demonstration. In the example provided, the client is accepted at the end of process execution.

Table 11 Activities labels, probabilities, and computation results

Activity	Symbol		Result		Probability (estimation)
	M	E	M	E	
Capturing customer data	a	A	2	1	1.0
Perform 1st round research	b	B	3	2	1.0
Accept integrity class as low	c	C	4	3	0.7
Perform 2nd round research	d	D	1	2	0.3
Perform 3rd round research	e	E	2	2	0.3
Accept integrity class	f	F	3	5	0.6
Reject the request	g	G	4	3	0.1
Inform customer	h	H	1	1	1.0
Update customer data	i	I	2	2	1.0
Update marketing	j	J	3	2	0.5

5

Activity	Symbol		Result		Probability (estimation)
	M	E	M	E	
Round up the process	k	K	0	1	0.2
Draft customer advice	l	L	2	3	0.2

In line with the BP-QC approach introduced in Section 5.2, the quality of the business process is computed in different iterative phases, namely: decomposition, computation, and aggregation. In the first phase, the business process is decomposed into different parts according to the patterns introduced in Section 5.3 (Figure 39). As can be observed from Figure 39[1], the patterns of sequential, exclusive, loop 1, parallel, and inclusive are present in the business process. The business process is decomposed into different parts on the basis of the identified patterns (i.e., decomposition).

Each pattern is reduced to a single activity and computed (i.e., computation). In this example, the reduction is performed in different stages to provide a better understanding of the approach. Each time a reduction is applied, the business process structure changes (i.e., aggregation). In each stage, a few parts are reduced to a single activity and computed. The end result is one single activity as illustrated in Figure 41.

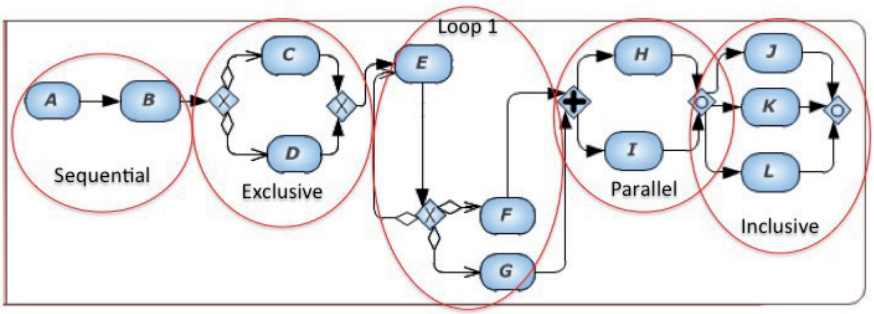


Figure 39 Patterns present in the business process

The computation is conducted both for measurement and estimation. Figure 40 depicts the instantiation for the measurement purpose; the activities executed in this instantiation are shown shaded. As observed, there is no loop iteration within this instantiation.

[1] For the sake of simplicity, the uppercase letters are used for both estimation and measurement in the diagrams.

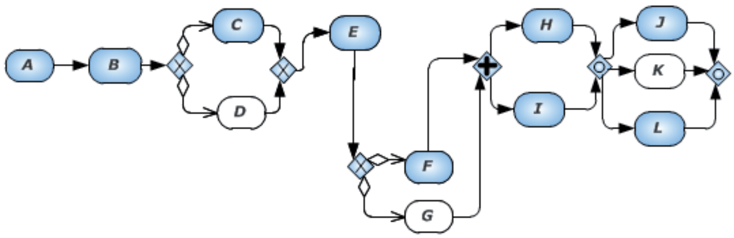


Figure 40 An instance of the business process

Either estimation or measurement of the activity flow is possible. Based on the reduction patterns, four steps toward complete reduction are involved in the calculation of cycle time (Figure 41). The result of reducing each set of activities is presented as another activity. The resulting activity label is indicated as the combination of the labels of the constituent activities; for example, in stage 1, reduction of the sequential pattern "A→B" is a single activity named "AB" and so on. In the reduction of the loop pattern, E is replaced with $\mathbf{a}_{EFG}$.

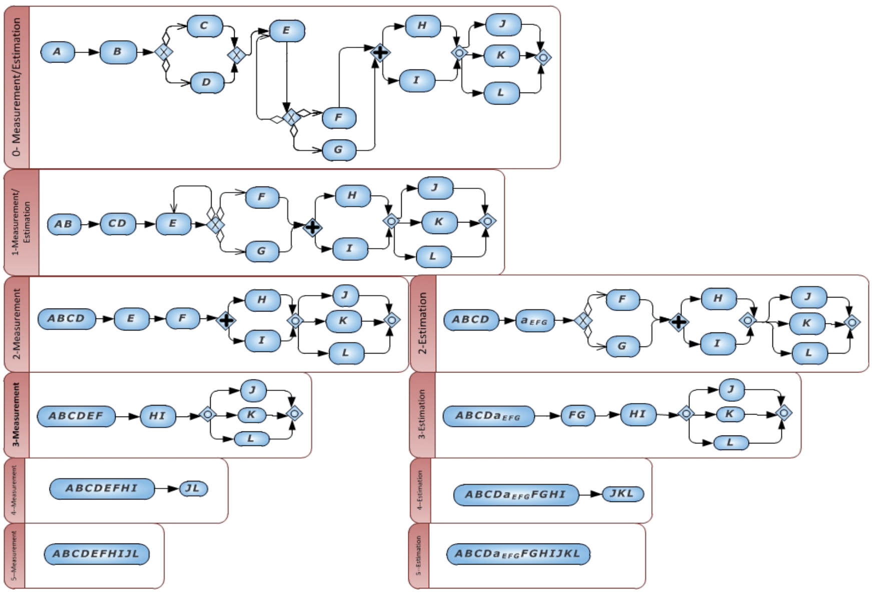


Figure 41 Stepwise reductions for estimation and measurement

Table 12 represents activity labels, the results of activity time measurement and activity time estimation (in weeks) and, if applicable, activity execution probability. For the inclusive patterns, four options exist: “J” with the probability of 50%, “K” with the probability of 20%, “L” with the probability of 20%, and “J and L” with the probability of 10%. Given the formulae introduced in Section 5.4, Table 12 provides the formulae for calculation of the activities resulting from each reduction stage in the case of measurement and in the case of estimation. Where applicable, a new probability is introduced. As demonstrated, computation of requirement fulfilment of a business process is based on the results of its constituent concepts.

Table 12 The business process (reduced parts) computation

Measurement			Estimation			
Activity	**Formula**	**M**	**Activity**	**Formula**	**P**	**E**
ab	t(a) + t(b)	5	**AB**	T(A) + T(B)	1	3
cd	t(c)	4	**CD**	T(C) * p(C) + T(D) * p(D)	1	2.7
abcd	t(ab) + t(cd)	9	**ABCD**	T(AB) + TCD)	1	5.7
fg	t(f)	3	**a_{EFG}**	T(E) / (1 - p(E))	1	2.86
abcdefg	t(abcd) + t(e) + t(fg)	14	**FG**	p_{new} (F) * T(F)+ p_{new} (G) * T(G) p_{new} (F)= p(F)/p(F)+p(G) p_{new} (G)= p(G)/p(F)+p(G)	p_{new}(F)= 0.857 p_{new}(G)= 0.143	4.71
hi	Max{t(h),t(i)}	2	**ABCDa_{EFG}**	T(ABCD) + T(a_{EFG})	1	8.56
abcdefghi	t(abcdefg) + t(hi)	16	**HI**	Max{T(H), T(I)}	1	2
jl	Max{t(j), t(l)}	3	**JL**	-----	0.1	----
abcdefghijl	t(abcdefghi) + t(jl)	19	**ABCDa_{EFG}FGHI**	T(ABCDa_{EFG}) + T(FG) + T(HI)	1	15.27
---	---	--	**JKL**	p(J) * T (J) + p(K) * T(K) + p(L) * T(L) + p (JL) * Max{T(J) , T(L)}	1	2.1
---	---	--	**ABCDa_{EFG}EFHIJKL**	T(ABCDa_{EFG}EG HI) + T(JKL)	1	17.37

P: Probability- M: Measurement-E: Estimation

Based on these results, the manager can see the gaps between real values, estimated values, and quality targets. In the current design of the business process and with the current process participants, the process is computed to take 19 weeks, based on measurements, and 17.37 weeks, based on estimates, whereas the requirement is to take at most 16 weeks. Given this gap, the manager might change either the business process or the requirement.

The benefit of this approach is that the computation is quantitative, and data-driven. This provides useful information for stakeholders: they know the actual performance of a business process, its estimated performance, and deviations from the given quality requirements. Moreover, knowing the quality of each single activity and of different parts of a business process enables managers to find out which concept or part of the process needs to be improved to improve the quality of the business process as a whole.

5.6. Conclusion and Future Work

This chapter provided an answer to the research question “Can the quality of a (part of) business process be computed on the basis of the results of computing quality of its constituent concepts?” The main contributions of this chapter are as follows:

- A conceptual framework to assist business process modellers and analysts to work in a systematic and generic manner when computing business processes. The framework establishes a set of conceptual structures and method steps, confined to neither a particular BPML nor a particular class of applications, and therefore having a wide range of applicability.
- A set of generic business process patterns decomposing business processes into more succinct parts. Decomposition according to a set of predefined, generic patterns fosters the generalisability of the approach.
- A set of computational formulae for the given patterns and quality dimensions, to facilitate the quantitative quality computation of a business process. The contribution of this approach is the enablement of carrying out a quantitative and data-driven analysis, which may be applied to a part or the whole of a business process.

Using the same criteria as those for evaluating the existing approaches, the approach is situated as high-level granularity focused, formal, language independent, generic, quantitative, and systematic. In BP-CQ, the focus of is on a business process as a whole or a part of it, indicating a high-level granularity. The approach relies on formal expressions of business processes in business process models. Representation of business processes via a BPML provides a formal expression; this fosters mutual understanding of a business process between different stakeholders. The approach is independent of any language, which makes the potential use of BP-CQ much wider than if it were tied to a specific

BPML. The utility of the approach is generic, that is, applicable to any application and within any domain. Besides, the approach is quantitative, and data-driven. The approach is systematic and provides a methodological means by which developers can compute the quality of business processes on the basis of the computational results of its constituent activities. In line with the items introduced in section 5.2, a set of phases is prescribed with details on the 'way of working' within each phase, that is: (a) focus of work, (b) required inputs, (c) expected outputs, (d) techniques used, and (e) support tools.

Being able to compute the quality of a business process based on its constituent activities has the following advantages:

- Quality estimation allows considering and evaluating alternative business process designs. A set of potential alternative business process designs can be generated and evaluated, with the objective of changing the business process to meet quality requirements and objectives.
- Quality measurement of small parts of a given business process allows for realisation of the bottlenecks and the parts that need more consideration.

Limitations of BP-QC are: (a) the approach relies on given data for computation of the business process, so the credibility of the data and the accumulation of possible deviations of the data is a concern, (b) given the business process integrating meta-model that is based on seven mainstream BPMLs (Heidari et al., 2013c), six patterns are recognised in this thesis; the list is not intended to be exhaustive and can be extended to enhance expressiveness of the approach, (c) the approach only covers business process models with properties of well-structuredness and well-behavedness, and (d) overlapping and embedded patterns demand further research.

Future research can be in the following directions. First, this part of the thesis establishes a framework upon which different methodological and technological developments may emerge, such as enhancement of a tool to support business process quality estimation and measurement. Second, strategic modelling approaches such as system dynamics could be coupled to business process modelling, using parametric definitions according to quality criteria and experimenting with 'what-if scenarios,' thus giving stakeholders an early view of the impact of their choices on the behaviour of a business process (Loucopoulos et al., 2003b). Third, the area of collaborative business process methods can be considered, to be able to deal with complex business processes involving many actors from different departments and maybe even different organisations. Finally, the metrics can be defined formally, based on XES facilitating the modelling and computation.

Part III: Application and Evaluation

Chapter 6. Approach to Application and Validation: AAV

…, It is not what you say, but how you say it.
– A. Putt

6.1. Introduction

Design science research is an embodiment of three closely related cycles of activity: relevance cycle, design cycle, and rigour cycle (Hevner and Chatterjee, 2010). The relevance cycle inputs requirements from the contextual environment into the research and introduces the research artefact into environmental field-testing (Figure 42). The rigour cycle provides grounding theories and methods along with domain expertise from the foundations knowledge base to the research and adds the new knowledge generated by the research to the growing knowledge base. The central design cycle supports a tighter loop of research activity for the construction and evaluation of research deliverables. This chapter elaborates on "*application in the environment*" of the "*relevance cycle*" as well as "*addition to the knowledge base*" of the "*rigour cycle*" to conduct application and validation of the research.

Evaluation includes the integration of the artefact within the technical infrastructure of the business environment. The evaluation of a designed artefact requires the definition of appropriate metrics and possibly the gathering and analysis of appropriate data (Hevner et al., 2004). An artefact is complete and effective when it satisfies the requirements and constraints of the problem it is meant to solve (Hevner et al., 2004). The relevance cycle defines acceptance criteria for the ultimate evaluation of the research results: does the research artefact improve the environment and how can this improvement be measured (Hevner, 2007). Considering the rigour cycle, additions to the knowledge base as results of research include research contributions (Chapter 3- 5), and all experiences gained from performing the research and evaluating the approach in the application environments (Chapters 7-10) (Hevner, 2007).

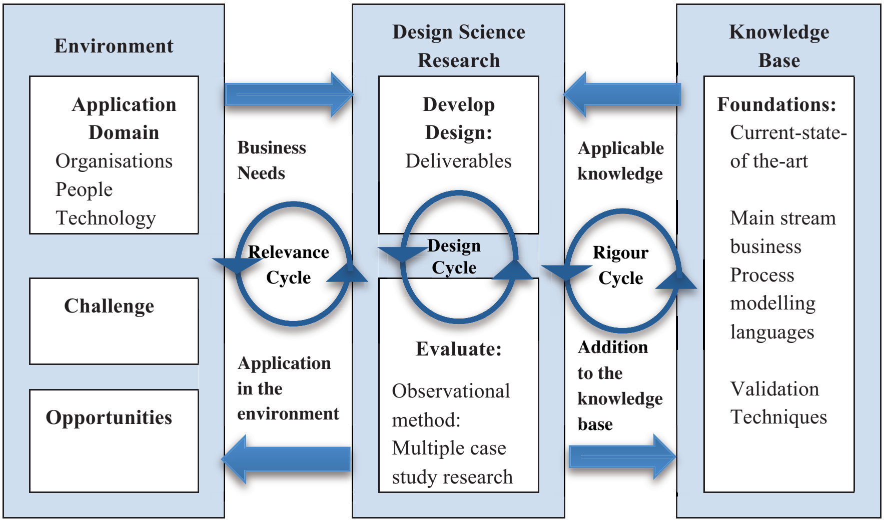


Figure 42 Application and validation focus in the design science research cycles

The goal of evaluation is to determine how well the artefact will perform in practice (Wieringa et al., 2012). The output from the design science research is returned back into the environment for study and evaluation in the application domain. The field study of the artefact can be executed by means of appropriate technology transfer methods, such as "case study method". Case study research is a useful means to study information systems development, implementation and usage in the field (Darke et al., 1998). In this thesis, a multiple case study is chosen, as an investigation of research deliverables in diverse settings (i.e., organisations) (Darke et al., 1998) with different stakeholders. Thus, multiple-case studies can strengthen research findings in the way that multiple experiments strengthen experimental research findings (Darke et al., 1998, Benbasat et al., 1987, Yin, 2003).

The following sub-sections elaborate on the approach to application and validation. Section 6.2 elaborates on the evaluation plan. Section 6.3 elaborates on the selection of contexts and stakeholders. Section 6.4 describes the case study plan, and Section 6.5 summarises the chapter.

6.2. Evaluation Plan

Evaluation involves comparing the objectives of a solution to actual observed results from using the research deliverables in a demonstration (Peffers et al., 2007). This chapter elaborates on the application and validation of the research deliverables[1]. Three main questions need to be answered:

1. What is evaluated?
2. How is it evaluated?
3. What is the procedure for evaluation?

As mentioned earlier, in this thesis a "multiple case study method" is considered as a study of the artefact (i.e., research deliverables) in a number of business environments (i.e. contexts). A plan is provided for the case study to answer the aforementioned questions. The plan involves application criteria to see if the research goals have been achieved. These criteria indicate *effectiveness* (i.e., has a change been achieved) and *utility* (i.e., has the change led to an improvement) (Wieringa and Morali, 2012). The plan describes:

1. Units of analysis (*What is evaluated?)*
2. A measurement model (*How is it evaluated?)* for:
   (a) Answering the knowledge questions, capturing:
      i. Evaluation of effectiveness of the implemented research deliverable in the context (*effectiveness* measures).
      ii. Opinion of the stakeholders on the utility and usefulness of the research deliverables (*utility* measures).
   (b) Data collection and analysis.
3. A generic procedure for the case study (*What is the procedure for evaluation?*).

This thesis focuses on four case studies in different contexts. Each case study focuses on one business process. The case studies are designed to focus on the evaluation of the major contributions of the thesis, namely the three research artefacts: the Business Process Integrating Meta-Model (BPIMM), Business Process Concept Quality Computation (BPC-QC), and Business Process Quality Computation (BP-QC)

6.3. Contexts and stakeholders

The relevance of any design science research effort is determined with respect to a constituent community. To be relevant to a community, research must address the problems faced and the opportunities afforded by the interaction of people, organisations, and information technology (Hevner et al., 2004). This section elaborates on the context, stakeholders, and their requirements in the case studies this thesis addresses.

[1] In this thesis, the terms "validation" and "evaluation" are used alternatively.

A context is defined as an environment that establishes requirements upon which the practical evaluation of an artefact is based, in this thesis the evaluation of the artefacts designed in the previous chapters, namely BPIMM (Chapter 1), BPC-QC (Chapter 4), and BP-QC (Chapter 5). This environment includes the technical infrastructure, which itself is incrementally built through the implementation of new artefacts. Evaluation includes the integration of these artefacts within the technical infrastructure of the environment (Hevner et al., 2004), satisfying the stakeholders' requirements. Therefore, by conducting the evaluation in this thesis, two interrelated aspects are taken into account in this thesis: (a) organisations and (b) stakeholders' requirements.

The contexts selected for evaluation of the research approach fulfil the following criteria:

- Criterion 1 - The organisation has an extensive experience in business process modelling.
- Criterion 2 - The organisation has an appreciation for research into the quality of business processes.
- Criterion 3 - The organisation has an appreciation for business process quality computation and is willing to introduce the proposed research artefacts BPIMM, BPC-QC and BP-QC in its practice.

For each of the case studies described in this thesis, both technology-oriented and management-oriented (business process) stakeholders are involved from different levels within their organisations (Table 13).

Table 13 Stakeholders overview

Context	ID	Role of the interviewee	Interview conduct
Organisation A (Educational and research institution)	A1	Senior financial controller	One-to-One
	A2	Finance and control information specialist	One-to-One
Organisation B (Global financial institution)	B1	Lean six sigma black belt	One-to-One
	B2	Lean six sigma black belt	One-to-One
	B3	Lean six sigma black belt	One-to-One
Organisation C (International financial service provider)	C1	Business process innovator	Telephone
	C2	Manager of business process analysis	Group

Context	ID	Role of the interviewee	Interview conduct
	C3	Business process analyst	Group
	C4	Business process analyst	Group
	C5	Business process analyst	Group
Organisation D	D1	Senior researcher, Program manager	One-to-One
	D2	Director/Change manager	One-to-One
	D3	CIO, Lector	Telephone

6.4. Case Study Plan

Evaluation entails understanding: (a) units of analysis, and (b) a measurement model that provides the quantitative or qualitative data needed to study the units of analysis (Wieringa and Morali, 2012).

6

6.4.1. Units of Analysis

The unit of analysis concerns the focus of the study (Benbasat et al., 1987). This can be an individual, a group, or an entire organisation, or it can be a specific programme, project, or even a decision. For this thesis, the research deliverables of this thesis are the units of analysis:

1- Business process integrating meta-model (BPIMM)
2- Business process concept quality computation (BPC-QC)
   i. Business Process Concept Quality Evaluation Framework (BPC-QEF) and algorithm
   ii. Quality factors
   iii. Quality metrics
3- Business process quality computation (BP-QC)
   i. Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm
   ii. Business process patterns
   iii. Computational formulae

For each unit of analysis, a set of evaluation measures (questions) is defined in the measurement model.

6.4.2. Measurement Model

Validation of a designed artefact requires the definition of appropriate metrics, as well as gathering and analysing appropriate data (Hevner et al., 2004). Knowledge questions have two orientations: *effectiveness* examined by the researcher, and *utility* examined by the stakeholders.

In evaluating *effectiveness* of the research artefacts BPIMM and BPCQ, the main validation questions are:

- Can the business process integrating meta-model *effectively* specify the business process model in the case study?
- Is the approach to computing the quality of business process concepts *effective?*
- Is the approach to computing the quality of business processes *effective?*

For each unit of analysis (research deliverable), in Part A a set of evaluation measures is defined as a detailed form of aforementioned questions.

To evaluate the *utility*, there is a need to involve the stakeholders and examine whether and to which extent their goals have been achieved (Wieringa and Morali, 2012). For this reason, after inserting an artefact into the context, the stakeholders' opinion on the *utility* of an artefact is captured, which demands knowledge acquisition. The main validation question is:

- Are the research artefacts BPIMM, BPC-QC and BP-QC perceived by the stakeholder as having added value and *utility*?

More detailed knowledge questions on utility are provided in Part B.

Part A: effectiveness

- **Evaluation of Business Process Integrating Meta-Model**

The goal is to provide a suitable answer to the question: *Can the business process integrating meta-model effectively specify the business process model in the case study?*

In each context, the business process targeted is represented in the organisation's preferred business process modelling language. The business process model is the input for the evaluation. The objective is to investigate if the concepts and relationships in each model can be mapped onto the BPIMM's concepts and relationships. A measure is developed for the evaluation, showing the percentage of concepts and relationships of the model that can be mapped onto the concepts and relationships in BPIMM:

$P_M = \frac{N_f}{N_C + N_r} \times 100$	P_M= Percentage of concepts and/or relationships in the model mapped to the concepts and/or relationships in BPIMM N_f=Number of concepts and/or relationships in the model that could be supported by the concepts and/or relationships in BPIMM N_C= Number of concepts in the model N_r=Number of relationships in the model

It is assumed that mapping a concept and mapping a relationship have the same importance.

➢ **Evaluation of the Approach to Business Process Concept Quality Computation (BPC-QC)**

The goal is to provide a suitable answer to the question: *Is the approach to computing quality of business processes concepts effective?*

With respect to the main evaluation question, detailed evaluation measures are defined for each research deliverable:

a. Business Process Concept Quality Evaluation Framework (BPC-QEF) and algorithm:

g) Are the conceptual model and method steps sufficient and effective in identification of concepts, factors, and metrics?

h)

b. Quality factors

i) Are the definitions of quality factors correct?

j) Do they suffice?

k)

c. Quality metrics

l) Are the definitions of the metrics correct?

m) Do they suffice?

➢ **Evaluation of the Approach to Business Process Quality Computation (BP-QC)**

The goal is to provide a suitable answer to the question: *Is the approach to computing the quality of business processes effective?*

a. Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm

n) Are the conceptual model and the method steps sufficient and effective for the purpose of computation?

b. Business process patterns

o) Are the definitions of the business process patterns correct?
p) Do they suffice?
q) Do all of the business process parts map 1-1 onto the proposed well-structured patterns?

c. Computational formulae

r) Are the computational formulae correct?
s) Do they suffice?

Part B: Utility

Case studies should result in the validation of evaluation criteria, such as the degree of acceptance by a stakeholder, the range of applicability, etc. The main knowledge questions to be asked about the utility of a proposed solution are (Wieringa et al., 2012):

- What is the improvement, overall, with respect to the current situation?
- Is the solution usable and useful for your organisation?
- What is the support for this solution in the organisation?

In addition, stakeholders are asked to answer questions about the following specific topics in semi-structured interviews:

- Relevancy and adequacy of the quality factors and dimensions.
- Usefulness, ease of use, and scalability of BPC-QEF and its algorithm.
- Reliability of the measurement and estimation results.

Extended knowledge questions are provided in the semi-structured interview protocol presented in Appendix C. Part 1 of the questions concerns background information and expertise of the interviewees. Part 2 investigates the relevancy and adequacy of the quality factors and dimensions. Part 3 focuses on usefulness, ease of use, and scalability of BPC-QEF and algorithm. Part 4 addresses reliability of the measurement results and estimation results. Part 5 concerns the overall usability and usefulness of the approach.

6.4.3. Data Collection and Analysis Methods

To collect data for a case study, three interrelated questions are of importance:

- What data should be collected?
- How to collect the data?
- Where to collect the data?

This thesis applies both first-degree and second-degree data collection methods (Lethbridge et al., 2005). The first-degree data collection method consists of design workshops and interviews. The second-degree data collection method consists of acquiring data from logs.

Design workshops

Conversational methods (Byrd et al., 1992) such as workshops are known to be effective for requirements analysis, as all the key stakeholders are in a room contributing to the analysis activity (Hossenlopp and Hass, 2007).

In the first design workshop stakeholders are informed on

- The research objective.
- The research artefacts to be evaluated: BPIMM, BPC-QC, and BP-QC to be evaluated.
- The unique selling points of the research artefacts.
- A comparison with the current measurement systems.
- An application of the research artefacts BPIMM and BP-CQ to a real-life business process.
- The potential benefits for the organisation.
- The potential benefit for the research community.

Management commitment for contributing resources to the evaluation is officially acquired and relevant confidentiality terms are agreed upon. Before the second design workshop, stakeholders are informed of: (a) the specific goal of the workshop, (b) documents/data required for the workshop, (c) time and duration of the workshop, and (d) required facilities (e.g., a smartboard, projector, etc.). During the design workshop, the researcher is in the lead and structures the workshop to focus on: (1) knowledge acquisition, on sharing the knowledge, (2) knowledge negotiation, targeting relevant points of contention, and (3) user acceptance of the end result (Walz et al., 1993). After the workshop, the result is sent to the stakeholders in a formal format (i.e., a workshop report[1]) asking for their approval.

Interviews

Open-ended interviews are semi-structured and each completed within 30 to 60 minutes. The open-ended interview is considered to combine the researcher's interest in the topic of the interview and in the interviewee's views and experiences, with the opportunity for the stakeholder to reflect on the approach and provide his/her insights into the findings. For the four case studies in this thesis, only two interviews are conducted via phone. A long established evidence (Rogers, 1976) denotes that phone interviews are just as effective as

[1] Template of workshop report is provided in Appendix D

face-to-face interviews. In this thesis, no limitations in the data collected is observed. The group interview encourages the interviewees in Organisation C to talk to one another, asking questions and commenting on each others' experiences and points of view (Kitzinger, 1995). The method is found to be useful in exploring the interviewees' knowledge and experience, providing mutual opinion, and generating more critical comments than individual interviews (Kitzinger, 1995). Audio recording of the interviews is conducted as a means to provide a complete description of the interviewees' responses and comments (Darke et al., 1998).

The structure and format are defined in the form of an interview protocol (Appendix C). The interviewees are informed beforehand about the research, interview, confidentiality, etc. through the information sheet (Appendix A), and their agreement on the participation in the interview and audio recording is officially acquired through signing the informed consent form (Appendix B). The interviewer is equipped with a "field kit" (Miles and Huberman, 1994), consists of (a) an audio recording device, (b) an information sheet, (c) a summary of the results of implementation where applicable, (d) the business process model under investigation, and (e) an interview protocol accompanied with a summary note template to take down effective notes during the interview.

A pilot interview is conducted to elicit free flowing information from the target stakeholders. For the interview analysis, the method introduced by (Miles and Huberman, 1994) is followed. Each interview is recorded and transcribed. The transcription is printed out and in a few iterations, the printout is read, relevant parts are coded manually, and overlapping or redundant codes are merged or omitted. The quantitative data analysis tool ATLAS.ti 7.0 is used to enable the researcher to keep track of the information collected and for the analysis to capture code and report the findings for each case study. Analysis of the case study data through coding the data thereby yields data nodes analysed further.

A starting set of codes are defined (Miles and Huberman, 1994) based on the case study measurement model of utility (e.g., usability and reliability of findings). The coding process is conducted in the following steps:

> ***Step 1:*** Coding the concepts introduced in the measurement model.
> ***Step 2:*** Analysing the interview data coded in the previous phase (i.e., extracting the data already coded under a certain concept), to affirm the soundness of the code assignment.

Table 14 provides the codes defined. Three sub-codes of "Positive" (+), "Negative" (-) and "In Between" (+/-) are defined for each code, demonstrating the attribute of the stakeholder's opinion on the approach.

Table 14 Codes and sub-codes for the qualitative data analysis.

	Sub-codes		
Codes	**Positive (+)**	**In between (+/-)**	**Negative (-)**
Relevancy of quality factors and dimensions for the business process	Strongly relevant	Fairly relevant	Irrelevant
Overall relevancy of quality factors and dimensions	Strongly relevant	Fairly relevant	Irrelevant
Adequacy of quality factors and dimensions	Strongly adequate	Fairly adequate	Inadequate
Ease of use of BPC-QEF and algorithm	Significantly easy	Fairly easy	Hard to use
Ease of learning BPC-QEF and algorithm	Significantly easy	Fairly easy	Hard to learn
Scalability of BPC-QEF and algorithm	Strongly scalable	Fairly scalable	Unsalable
Coherency of BPC-QEF and algorithm	Strongly coherent	Fairly coherent	Uns coherent
Reliability of the measurement results	Strongly reliable	Fairly reliable	Unreliable
Reliability of the estimation results	Strongly reliable	Fairly reliable	Unreliable
Overall usefulness of the approach	Significantly useful	Fairly useful	Useless
Improvement with respect to the current situation	Significantly improved	Fairly improved	Unimproved
Overall usability of the approach	Significantly usable	Fairly usable	Unusable
Support required for implementation	A significant amount of support required	A fair amount of support required	No support required

To report on the findings of the qualitative data analysis, an explanatory method is followed, allowing the researcher to factually record and draw inferences from the interview data (Cunningham, 1997). A factual report is provided from the interview data analysed by coding the data through the use of the ATLAS.ti 7.0 tool. Each statement in the report is accompanied by a closed parenthesis following this format: [#code of the interviewee: #Text Fragment Number in the transcript (T)] supporting the statement. Quotations from different stakeholders are separated by a "/" sign.

To enhance the reliability of the findings, a senior researcher checks the interview transcripts and reports on coding and the final report. The senior researcher is an associate professor, with more than eight years of experience after obtaining his PhD, who is not a member of the supervisory committee of the PhD researcher.

6.4.4. Procedure for Application and Validation

Within each case study, a specific business process is studied in a specific context. The following generic procedure is defined for conducting the application and validation. Phases 1 to 6 are conducted in design workshops and phase 7 in interviews:

1- ***Phase 1:*** Context, stakeholders and environment.
2- ***Phase 2:*** The business process integrating meta-model specification of the business process.
3- ***Phase 3:*** Specification of quality requirements, related factors, and metrics.
4- ***Phase 4:*** Data acquisition – real data and estimation.
5- ***Phase 5:*** Quality computation of the business process.
6- ***Phase 6:*** Evaluation of the results.
7- ***Phase 7:*** Evaluation of the approach by individual stakeholders.

In practice, in real-life situations factors such as timely access to stakeholders, access to data sources, and availability of complete and correct data/estimations, have not always been feasible due to organisational constraints. The focus and scope of individual case studies has therefore been adapted when needed and detailed in the relevant chapters.

6.5. Chapter Summary

This chapter elaborates on the approach followed in this thesis to the application and validation of the research. Through four case studies, the research artefacts BPIMM, BPC-QC, and BP-QC are evaluated in different contexts and by different stakeholders. The approach includes a selection of units of analysis, a measurement model for those units of analysis, methods to collect data in accordance with the measurement model, and a procedure to apply these methods in a case study. Furthermore, the approach provides a method to analyse the value of the findings of the case studies.

Chapter 7. Case Study Organisation A

Whenever anyone says, 'theoretically,'
they really mean, 'not really.'
-Dave Parnas

7.1. Introduction

This chapter elaborates on a case study conducted within Organisation A for one specific business process. The goal of this case study is to evaluate the usefulness and usability of the research artefacts BPIMM, BPC-QC, and BP-QC designed in this thesis for this context, using the case study measurement model provided in Chapter 6. The guidelines listed in Chapter 6 are leading.

This chapter is organised as follows. Sections 7.2 to 7.5 introduce the implementation of the case study: describing the context, stakeholders, and requirements, agreeing on the representation of the business process, mapping the business process onto the BPIMM, specifying the requirements, and computation for BPC-QC and BP-QC. Section 7.6 conducts an evaluation on effectiveness, and Section 7.7 provides an evaluation on utility. Section 7.8 provides a summary of the chapter.

7.2. Context, Stakeholders and Environment

The context is a large Dutch educational and research organisation, referred to as Organisation A throughout the thesis. The organisation provides direct services to ten thousands individuals, and has thousands of staff. Stakeholders with technology and management orientations are involved in the evaluation of the utility of the research artefacts proposed in this thesis. The roles of the stakeholders are shown in Table 15.

Table 15 Organisation A stakeholders involved in the evaluation as interviewees

ID	Role of the interviewee	Years of experience	Years of experience in the organisation	Interview conduct
A1	Senior financial controller	28	20	One-to-One
A2	Finance and control information specialist	20	14	One-to-One

Given the priorities of the organisation, the business process "Dealing with an invoice" has been chosen for this case study. As a response to a recent change in EU requirements, Organisation A is obliged to pay invoices within 30 days of a claim (invoice submission). At the moment, however, Organisation A does not have a means to measure fulfilment of this requirement. Moreover, Organisation A is interested in improving the quality of the business process as currently implemented. The Financial Department is responsible for this business process.

In the first workshop, stakeholders are provided with sufficient details about the research deliverables and implementation of BPIMM, BPC-QC, and BP-QC to the organisational context. An illustrative example of a business process is presented in detail to demonstrate the applicability of the approach. The business process model is created by the management (i.e., the process owner) in BPMN, which is a standard and mainstream business process modelling language. This modelling language is used throughout the case study for the representation of the business process and computational purposes. Details of the business process are communicated to the researcher.

7

The researcher investigates the business process, and discusses and solves the ambiguities with the stakeholders in a second workshop where both management and technology-oriented stakeholders are present. Different means of presentation, such as a smartscreen and whiteboard, are used to support the discussion. As a result, the business process and its representation in BPMN is agreed upon between the stakeholders as well as between the stakeholders and the researcher. Figure 43 depicts the BPMN model of the business process.

As can be observed in Figure 43, actors from different sectors, various software modules ('Basware') as well as a supplier are involved in business process execution. Submission of an invoice by a supplier is the trigger of the business process. The intended output is "a paid invoice" for which all rules and requirements are met; in other words, the content of the invoice should meet Organisation A's rules and requirements, otherwise the business process ends without paying the invoice. The business process can end unsuccessfully if there is a problem with the invoice that cannot be fixed. There are several decision points in the process, of which some can cause a loop with several iterations.

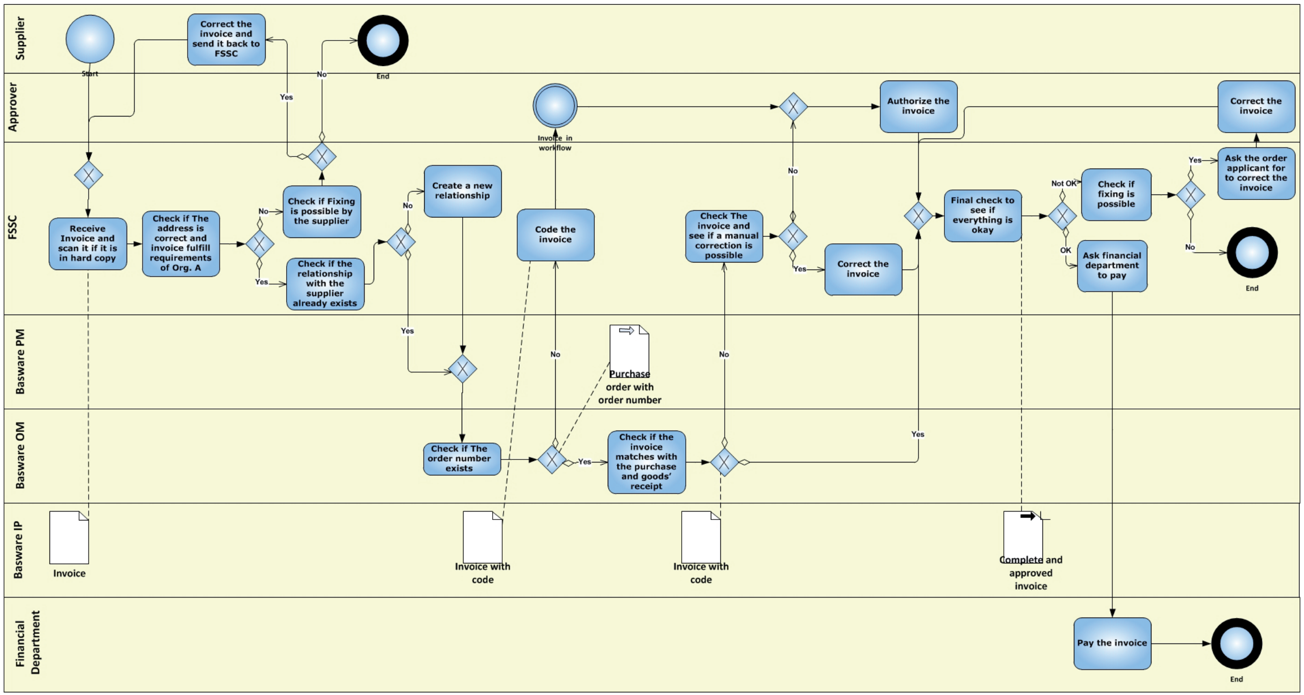


Figure 43 Business process model of "Dealing with an invoice"

7.3. The Integrating Meta-Model Specification of the Business Process

In the business process depicted in Figure 43, the following concepts are identified: lane, start event, end event, intermediate event, exclusive event, gateway, atomic activity, data object output, association, sequence flow, and conditional sequence. These concepts and their relationships can be mapped 1-1 with the concepts and relationships identified in the integrating meta-model BPIMM.

7.4. Specification of Quality Requirements and Factors

For the specification of the quality requirements, the researcher highlights that specifications can be defined at different levels of granularity, namely the business process activity level, business process part level, and the business process level. Step by step (following BPC-QEF), the business process flow for "Dealing with an Invoice" is reviewed and stakeholders brainstorm about their requirements and objectives. The researcher documents the requirements on the whiteboard and does not interfere or influence the discussion between stakeholders. The researcher then presents the list of quality factors introduced in Chapter 4 to examine if the stakeholders' initial list of requirements should be extended. The result is an agreed list of quality requirements, with a quality factor, (quantitative) target(s) and if applicable an activity for each quality requirement as depicted in Table 16. These results together with the pictures and notes taken during the session are sent to the stakeholders for official approval.

Highlights:

- In general, the system is designed in such a way that authority cannot be violated. Authority cannot be violated in the activity “authorise the invoice,” as only the authorised person has permission within the system to execute this activity. Access codes (passwords) are controlled by the authorisers.
- The stakeholders agree that the bottleneck of the business process is checking if an invoice meets the requirements of Organisation A and in making corrections.
- The cost of the business process execution is related to the time spent on the business process, due to its administrative purpose.

In the following subsections, the computations at the business process concept level and at the business process level are explained.

Table 16 The Financial Department requirement specification

No	Quality requirement	Quality factor	Target	Level	Activity	Remark
1	Invoices should be paid within 30 days after submission of the invoice (start of the process).	Cycle time	At most 30 days	Business process	---	Including weekend and holidays
2	Authorising invoices should be executed as fast as possible.	Cycle time	Rector: Max 4 days Dean: Max 2 days Head of Dep.: Max 2 days Head of section: Max 1 day Secretary: Max 1 day	Activity	Authorise invoice	Working days
3	Quality of information on the invoices should improve (Completeness and correctness in terms of addresses and the requirements of Organisation A).	N/A	At least 80% of the submitted invoices should meet the required quality	N/A	N/A	New quality factor is introduced and is measured indirectly
4	The number of invoices with an order number should increase.	N/A	At least 80%	N/A	N/A	New quality factor is introduced and is measured indirectly
5	Creating a new relationship should be done as fast as possible.	Cycle time	At most 1 day	Activity	Create new relationship	Working days
6	Failure in coding invoices should be reduced	N/A	At Most 20%	N/A	N/A	New quality factor is introduced and is measured indirectly

7.5. Quality Computation of the Business Process

In this case study, three computations are conducted: measurement at the concept level, measurement at the business process level and estimation at the business process level are conducted. The following sections elaborate on each computation.

7.5.1. Measurement at the Concept Level

As can be observed from Table 16, some quality requirements cannot be measured directly through the formulae introduced in Chapter 4. However, these requirements can be measured indirectly.

The goal is to improve the quality of information in invoices in terms of completeness and correctness in line with the requirements of Organisation A. Quality of information, as such, is outside the scope of this thesis. However, this aspect of quality can be measured indirectly as the proportional of the number of submitted invoices that are not returned back to suppliers in a certain period of time (determined by the stakeholders). This quality value can be represented by a percentage. This metric is not defined in the thesis and its introduction can be considered as an extension of BPC-QEF in response to this specific case.

Another requirement is that "The number of invoices with an order number should increase." This can be measured as the percentage of the invoices that need coding in relation to the total number of invoices submitted in a certain time span (determined by the stakeholders).

The stakeholders also defined "Failure in coding invoices should be reduced" as a requirement. This requirement relates to the total number of invoices coded. The initial failure frequency metric defined in the thesis is time-based, implying that the number of failures is calculated for a certain time period. A new metric has been added to express the percentage of failures related to the number of instances. The measurement can also be done indirectly and be represented as the number of corrections required in the business process.

For the above quality requirements, the stakeholders are asked to provide the following data (second-degree data) for computation:

1. The cycle time of "authorise the invoice" activity instantiations for different actors with different levels of authorisation.
2. In a certain time span (stakeholders can decide on this), the total number of invoices received and the number of instances of the activities "correct the invoice" and "correct the invoice and send it back to FSSC."

3. In a certain time span (stakeholders can decide on this), the number of instances of the activities "code invoice" and "check if the invoice matches with the purchase and goods receipt."
4. In a certain time span (stakeholders can decide on this), the number of instances of the activity "correct the invoice."

The results of measuring the quality factors based on the metrics discussed above are provided in Table 17 Business Process Concept Quality Measurement.

Given the quality requirements stated in Table 16 and the quality formula in Table 14 as input for BPCQ introduced in Chapter 4, the quality of the corresponding activities in the business process is measured. The measurement is conducted over ten instantiations of the business process. These results show the current situation for each of the quality factors. The results are communicated to the stakeholders, so that they can see the gap between the current situation and the quality target. For example, there is a large amount of delay in execution of the activity "Code the invoice."

Table 17 Business Process Concept Quality Measurement

No	Concept(s)	Quality Factor	Formula	Legend	Target		Result
1	Authorise the invoice	Cycle time	t(m) = dd(m)+ pd(m)	m= Authorise the invoice t(m)= cycle Time of authorising the invoice dd(m)= Delay Duration of authorising the invoice pd(m)= Processing Duration of authorising the invoice	Rector	Max 4 days	Not Available
					Dean	Max 2 days	2;77
					Head of Dep.	Max 2 days	8
					Head of section	Max 1 day	2;4;16;11
					Secretary	Max 1 day	1;7;1
2	Activity "Check if the relationship with the supplier already exists" Activity "Check if fixing is possible by the supplier"	Number of activity instances	o(in)= n(f) / [n(e) + n(f)]	q(in)= Quality of invoice (indirect metric) n(e)= Number of instances of "Check if fixing …" in a certain period of time n(f)= Number of instances of "Check if the relationship.." in a certain period of time n(e)+n(f)= Total number of instances/invoices	At least 80%		100%
3	Activity "Code the invoice"	Number of activity instances	pe(in)= n(j) / [(n(j)+n(I))]	pe(in)= Percentages of submitted invoices with code n(j)= Number of instances of "Check	80%		100%

No	Concept(s)	Quality Factor	Formula	Legend	Target	Result
	Activity "Check if the invoice matches with the purchase and goods receipt"			if the invoice…" in a certain period of time n(i)= Number of instances of "Code the invoice" in a certain period of time n(j)+n(i)= Total number of instances /invoices		
4	Activity "Create new relationship"	Cycle time	t(g) = dd(g) + pd(g)	g=Create new relationship t(g)= cycle Time of creating new relationship dd(g)= Delay Duration of Create new relationship pd(g)= Processing Duration of Create new relationship	1 day	1,2,5,0,13,12, 4,3,6,6,20
5	Code the invoice	Failure frequency	$ff(i) = n_f(i)/n(i)$	ff(i)= Failure Frequency in coding the invoices (indirect metric) $n_f(i)$=Number of failures that occurred in coding the invoices n(i)=Total number of coding the invoices	At most 20%	0%
	Check if fixing is possible		ff(i) = n(o)/n(n)	n(o)=Number of instances of the activity "Check if fixing is possible" n(n)= Number of instances of the activity "Final check to see if everything is okay"		
	Final check to see if everything is okay					

7.5.2. Estimation at the Business Process Level

Different scenarios can be considered for estimating the cycle time of the business process. In general, there are different variables that can be considered in the definition of the scenarios:

a) **Role of the authoriser in the organisation:** Authorising the invoices should take at most between 1 to 4 working days, depending on the role of the authoriser (i.e., one day for a secretary or a section head, two days for a department head or a dean, and four days for the rector).
b) **Result of the business process:** Either a business process results in a payment, or a problem exists with an invoice that cannot be fixed, in which case the process ends with no payment.
c) **Number of loop iterations in the business process:** Either the number of iterations is unlimited, or there is a maximum of two iterations for each loop (according to the stakeholders' specifications).

Combining these variables yield twelve scenarios to be estimated. The computations for scenarios (1) to (6) (Part A) provide the average time of the business process execution, including the possibility that an invoice cannot be paid. Handling such an invoice is included in the estimations, and incorporating the chances of not being paid reduces the estimated time of the business process. As the EU rule demands that invoices must be paid within a certain amount of time, the computation of the business process that leads to non-payment should be conducted separately. For this reason, this separate business process is extracted from the original one in Part B (Scenario 7 to 12) for the purpose of calculation. For the matter of space, only the computational details for two scenarios (Scenario 1 and 7) are provided, and for the other scenarios the results are presented, where needed, with tailored formulae for estimation.

Part A: Estimating the Business Process with the Option of not Paying the Invoice (Scenario 1-6)

Scenario (1): A business process with the option of not paying the invoice, with an unlimited number of loop iterations and having a secretary or a section head as the authoriser

In line with the BP-CQCF (Business Process Compositional Quality Computation Framework) approach introduced in Section 4.2, the cycle time of the business process is estimated from the estimated cycle time values of all activities and their estimated probabilities. For ease of communication, the name of each activity is replaced by an English alphabetic letter. The stakeholders provide the cycle time for each constituent activity and the probability of each outgoing branch (Table 18). Activities "M" and "O" belong to the parts constituting embedded patterns; thus, the probabilities have to be specified during the estimation of the whole business process.

Table 18 Estimation of the cycle times of activities (in working days) and their probabilities

No	Activity	Symbol	Probability	Cycle time
1	Correct the invoice and send it back to FSSC	B	90%	3
2	Receive invoice and scan it if it is hardcopy	C	100%	3
3	Check if the address is correct and the invoice fulfils requirements of Organisation A	D	100%	3
4	Check if fixing is possible by the supplier	E	50%	3
5	Check if the relationship with the supplier already exists	F	50%	3
6	Create a new relationship	G	20%	2
7	Check if the order number exists	H	100%	1
8	Code the invoice	I	85%	1
9	Check if the invoice matches with the purchase and goods receipt	J	15%	1
10	Check the invoice and see if a manual correction is possible	K	80%	1
11	Correct the invoice	L	40%	1
12	Authorise the invoice	M	Embedded	1
13	Final check to see if everything is okay	N	100%	1
14	Check if fixing possible	O	10%	1
15	Ask Financial Department to pay the invoice	P	90%	1
16	Correct the invoice	Q	95%	1
17	Ask the order applicant to correct the invoice	R	95%	1
18	Pay the invoice	S	90%	3

The computation distinguishes different iterative phases, namely: decomposition, computation, and aggregation. In the first phase, the business process is decomposed into different parts according to the patterns introduced in Section 5.3 (i.e., decomposition). Each part is reduced to a single activity and computed (i.e., computation). The label of the resulting activity is indicated via a series of letters, mostly taken from the combination of the constituent activities' symbols. There is no specific rule followed in labelling. The end result is one single activity, as illustrated in Figure 44 and Figure 45.

As can be observed, the business process has parts with embedded patterns. Computation of these parts is challenging, as there is no formal solution offered in the research. The solution chosen to overcome this problem is to realise different sequence flows and restructure the part in a way that the new part matches the patterns. The new parts are equivalent to the original parts. Where needed, new probabilities are calculated. In Figure 44 and Figure 45, the business process with the new structure is provided in the same row as the original structure.

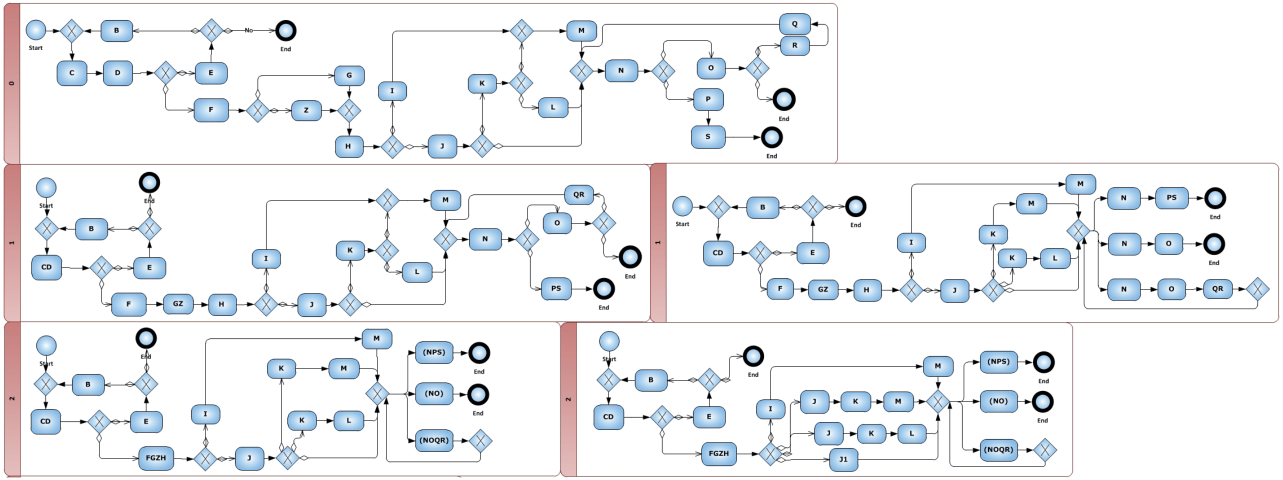


Figure 44 Stepwise reductions for estimation (steps 1 and 2)

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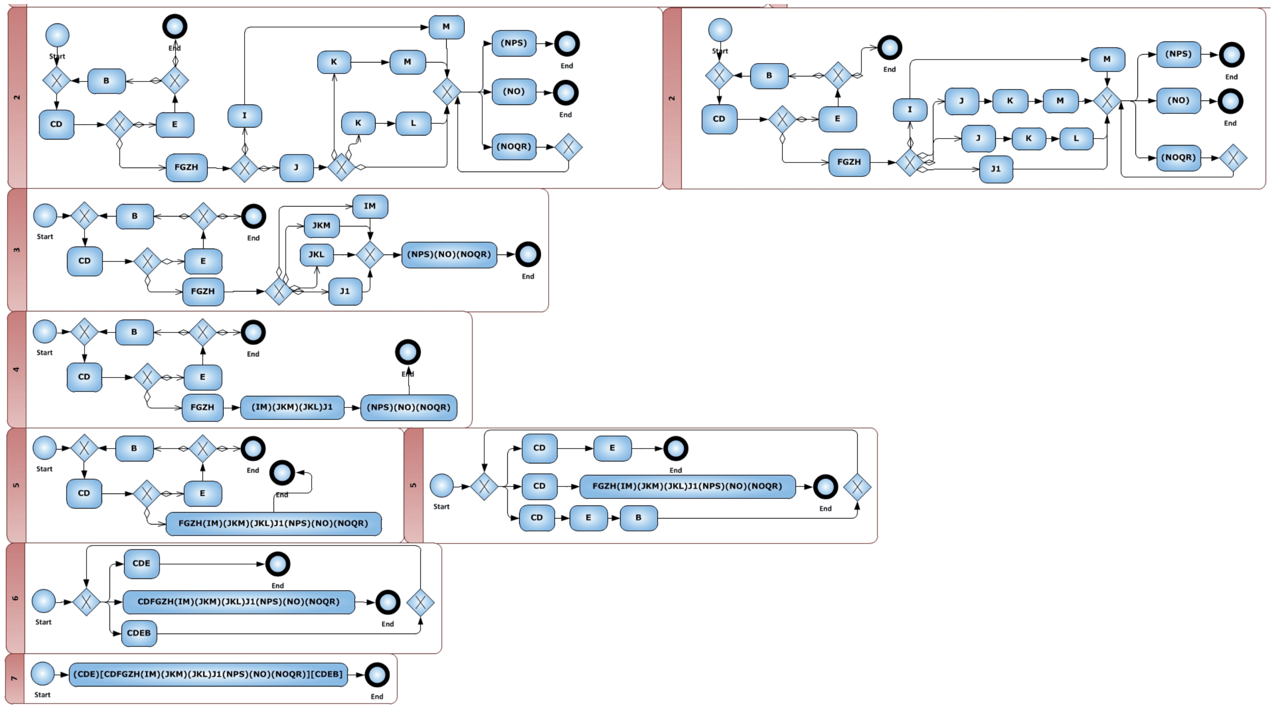

Figure 45 Stepwise reductions for estimation (steps 2-7)

Table 19 provides the formulae for cycle time estimation of the activities resulting from each reduction step.

Table 19 Cycle time estimation of "Dealing with an invoice"

Step	Reduction/ Restructuring result	Probability due to restructuring	Reduction Formula	Result
1	CD	---	T(C) + T(D)	6
	GZ	---	P(G) × T(G)	0.4
	PS	---	T(P) + T(S)	4
	QR	---	T(Q) + T(R)	2
	K,M	P(K) × [1-P(L)]	---	0.48
	K,L	P(K) × (P(L)	---	0.32
	N, PS	P(P)	---	0.9
	N,O	P(O) × [1-P(R)]	---	0.005
	N,O, QR	P(O) × P(R)	---	0.095
2	FGZH	---	T(F) + T(GZ) + T(H)	4.4
	(NPS)	---	T(N) + T(PS)	5
	(NO)	---	T(N) + T(O)	2
	(NOQR)		T(N) + T(O) + T(QR)	4
	J,K,M	P(K,M) × P(J)	---	0.072
	J,K,L	P(K,L) × P(J)	---	0.048
	J1	P(J) × [1-P(K,M)-P(K,L)]	---	0.03
3	(NPS)(NO)(NOQR)	---	$\{\sum_{i=1}^{2}[P(N,O,QR)]^{i}\times T(NOQR)\}+$ $[P(N,O)\times T(NO)]+$ $[P(N,PS)\times T(NPS)]$	4.93
	JKM	---	T(J) + T(K) + T(M)	3
	JKL	---	T(J) + T(K) + T(L)	3
	IM	---	T(I) + T(M)	2
4	(IM)(JKM)(JKL)J1	---	[P(I) × T(IM)] + [P(J,K,M) × T(JKM)]+[P(J,K,L) × T(JKL)] + [P(J1) × T(J)]	2.09

7

Step	Reduction/ Restructuring result	Probability due to restructuring	Reduction Formula	Result
5	FGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)	---	T(FGZH) + T[(IM)(JKM)(JKL)J1] + T[(NPS)(NO)(NOQR)]	11.42
	CD, E		---	0.05
	CD, FGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)		---	0.5
	CD, E, B		---	0.45
6	CDE	-----	T(CD) + T(E)	9
	CDFGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)		T(CD) + T[FGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)]	17.42
	CDEB		T(CD) + T(E) + T(B)	12
7	(CDE)[CDFGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)] (CDEB)	-----	$\{[\sum_{i=1}^{\infty} P(CD,E,B)]^{i} \times T(CD,E,B)\} +$ $[P(CD,E) \times T(CDE)] +$ $[P(F) \times T(CDEFGZ...R)]$	18.99≅ 19

As demonstrated, estimation of the requirements' fulfilment by a business process is based on the results of the constituent activities. Moreover, the estimation is carried out in a systematic and repeatable manner. This provides a quantitative and data-driven estimation. As can be observed from the table, with the current design of the process and the current process participants and resource allocation, it is estimated that the process takes nineteen working days on average, while authorisation of the process just takes one day (conducted by heads of sections or secretaries). Taking into the account the weekends, for each integer proportion of five days, two days should be added to the results. Thus, the business process will take twenty five days in total if it is started on a Monday or a Tuesday, otherwise it will take twenty seven days.

Scenario (2): A business process with the option of not paying the invoice, with an unlimited number of loop iterations and having a department head or a dean as the authoriser

If authorisation takes two days, the process will take twenty six days if started on a Monday; otherwise, it will take twenty eight days.

Scenario (3): A business process with the option of not paying the invoice, with an unlimited number of loop iterations and having the rector as the authoriser

If the authorisation takes four days, the process will take twenty nine days, independent of the weekday it started.

Scenario (4): A business process with the option of not paying the invoice, with a limited number of loop iterations and having a secretary or a section head as the authoriser

In scenarios 1 to 3, it is possible that the business process stays in a loop for an infinite number of times. However, according to the business process owners, each loop is executed either one or two times. Therefore, the following formulae are defined for those specific situations (Table 20):

Table 20 The number of loop iterations limited to one or two

Reduction/ Restructuring result	Two loops	Result	One loop	Result
(NPS)(NO)(NOQR)	$\left\{\sum_{i=1}^{2} [p(N,O,QR)]^i \times T(NOQR)\right\} + [P(N,O) \times T(NO)] + [P(N,PS) \times T(NPS)]$	4.9	$[P(N,O,QR) \times T(NOQR)] + [P(N,O) \times T(NO)] + [P(N,PS) \times T(NPS)]$	4.9
(CDE)[CDFGZH (IM)(JKM)(JKL)J1(NPS) (NO)(NOQR)] (CDEB)	$\left\{\sum_{i=1}^{2} [p(CD,E,B)]^i \times T(CDEB)\right\} + [P(CD,E) \times T(CDE)] + [P(F) \times T(CDEFGZ \ldots. R)]$	16.99≅ 17	$[P(CS,E,B) \times T(CDEB)] + [P(CD,E) \times T(CDE)] + [P(F) \times T(CDEFGZ \ldots R)]$	14.5≅ 15

Considering the weekends, the business process takes between nineteen days and twenty five days, depending on which day of the week it started and if there are limited number of loops in its execution.

Scenario (5): A business process with the option of not paying the invoice, with a limited number of loop iterations and having a department head or a dean as the authoriser

If the authorisation takes two days, the process will take nineteen days to twenty six days, depending on which day of the week it started and how many loop iterations occur in its execution (with a maximum of two days for each potential loop iteration).

7

Scenario (6): A business process with the option of not paying the invoice, with a limited number of loops and having the rector as the authoriser

If the authorisation takes four days, the process will take twenty two days to twenty seven days, depending on which day of the week it started and how many loop iterations occur in its execution (with a maximum of two days for each potential loop iteration).

Estimating the Business Process Ending with Payment (Scenario 7-12)

In this process, where it is needed, corrections are possible (Figure 46). For the new business process, the result of reduction is also one single activity, as illustrated in Figure 47 and Figure 48. Scenarios (7) to (12) correspond to specific descriptions of the new business process.

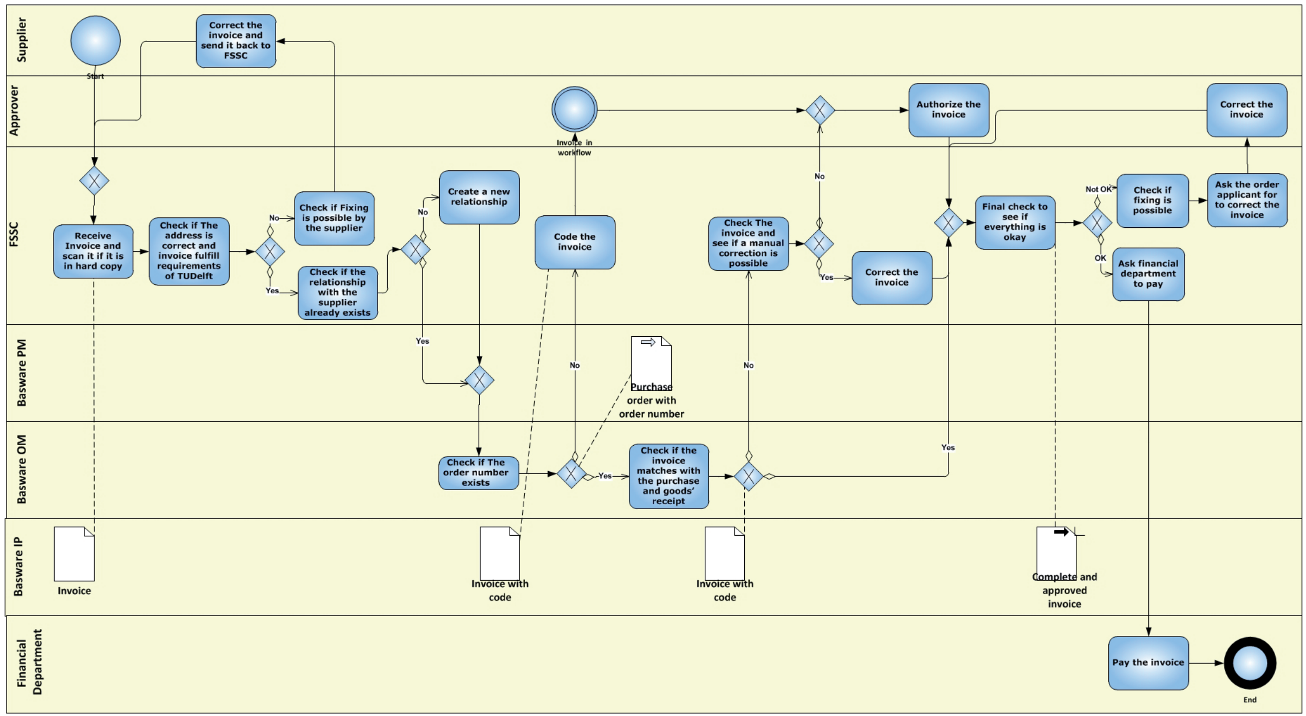

Figure 46 Business process "Dealing with an invoice" ending with payment

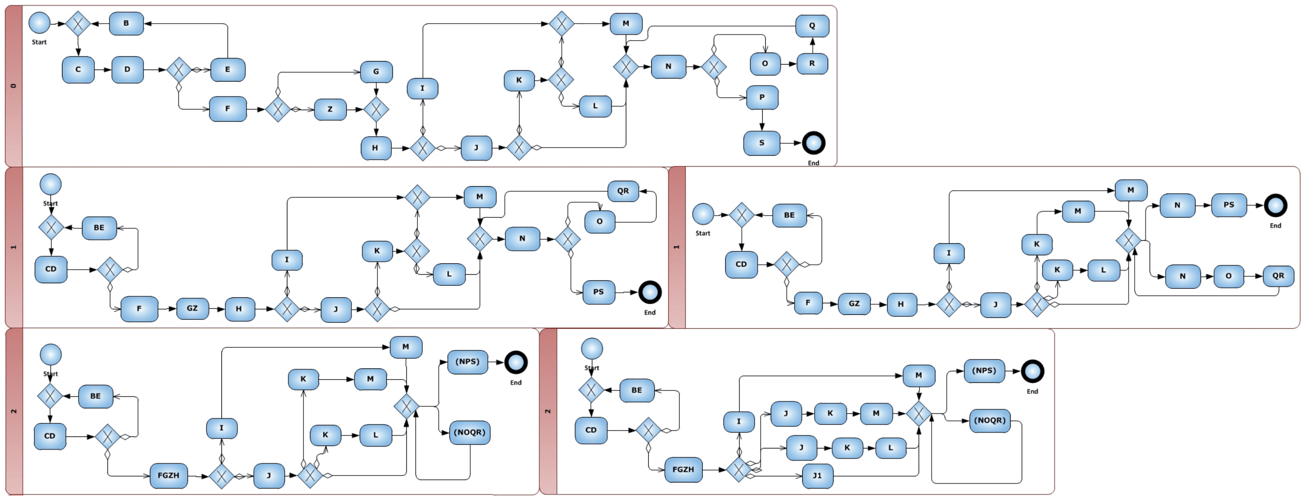

Figure 47 Reduction for the business process ending with payment (steps 1 and 2)

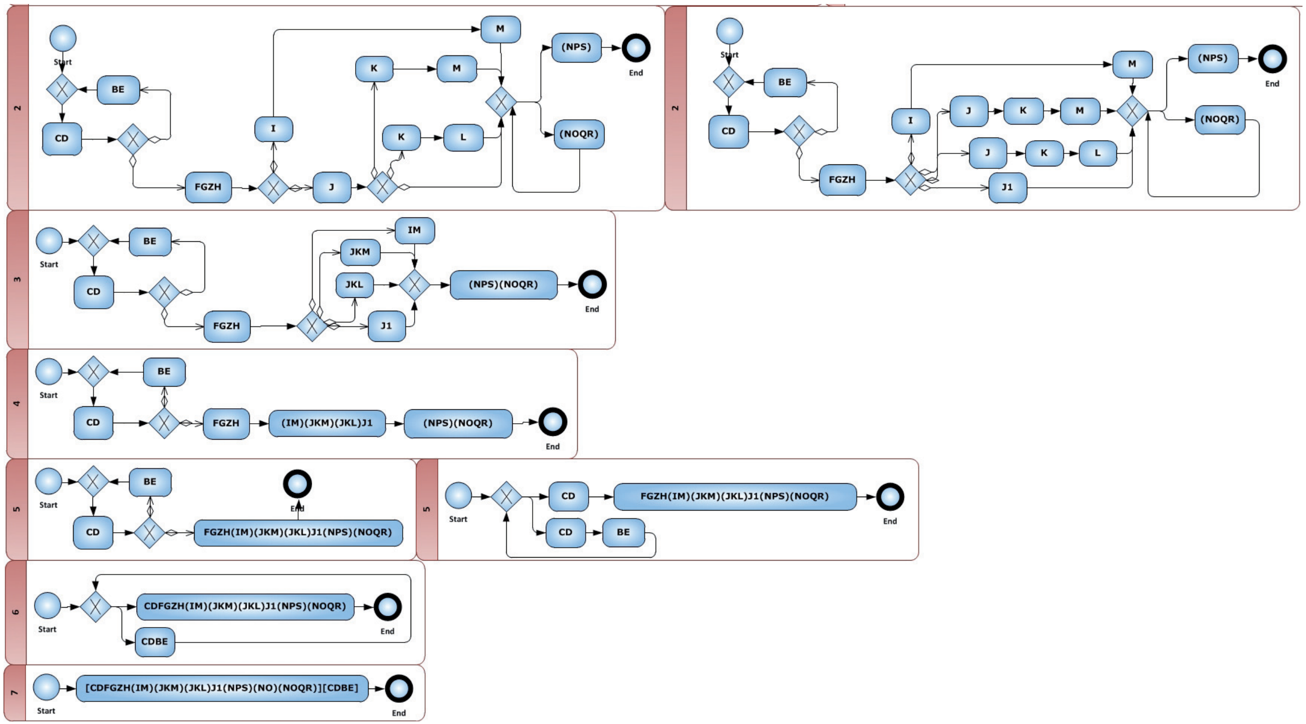

Figure 48 Reduction for the business process ending with payment (steps 2-7)

Scenario (7): A business process leading to payment, with an unlimited number of loops and having a secretary or a section head as an the authoriser

Table 21 provides the formulae for cycle time estimation of the activities resulting from each reduction stage. As demonstrated, the estimation of the fulfilment of payment requirements is based on the results of the constituent activities.

Table 21 Cycle time estimation of "Dealing with an invoice" resulting in payment

Step	Reduction/ Restructuring result	Probability due to restructuring	Reduction Formula	Result
1	CD	---	T(C) + T(D)	6
	GZ	---	P(G) × T(G)	0.4
	PS	---	T(P) + T(S)	4
	QR	---	T(Q) + T(R)	2
	K,M	P(K) × [1-p(L)]	---	0.48
	K,L	P(K) × (P(L)	---	0.32
	N, PS	P(P)	---	0.9
	N,O, QR	P(O) × P(R)	---	0.1
2	FGZH	---	T(F) + T(GZ) + T(H)	4.4
	(NPS)	---	T(N) + T(PS)	5
	(NOQR)	---	T(N) + T(O) + T(QR)	4
	J,K,M	P(K,M) × P(J)	---	0.072
	J,K,L	P(K,L) ×P(J)	---	0.048
	J1	P(J) × [1-P(K,M) - P(K,L)]	---	0.03
3	(NPS)(NO)(NOQR)	---	$\left\{\sum_{i=1}^{\infty} [p(N,O,QR)]^i \times T(NOQR)\right\} + [P(N,PS) \times T(NPS)]$	4.9
	JKM	---	T(J) + T(K) + T(M)	3
	JKL	---	T(J) + T(K) + T(L)	3
	IM	---	T(I) + T(M)	2
4	(IM)(JKM)(JKL)J1	---	[p(I) × T(IM)] + [p(J,K,M) × t(JKM)] + [p(J,K,L) × T(JKL)] + [p(J1) × T(J)]	2.09
5	FGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)	---	T(FGZH) + T[(IM)(JKM)(JKL)J1] + T(NOQR)	11.43

Step	Reduction/ Restructuring result	Probability due to restructuring	Reduction Formula	Result
	CD, FGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)	P(F)	---	0.5
	CD, E, B	P(E) × P(B)	---	0.5
6	CDFGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)	-----	T(CD) + T[FGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)]	17.43
	CDEB	-----	T(CD) + T(E) + T(B)	12
7	(CDE)[CDFGZH (IM)(JKM)(JKL)J1(NPS)(NO)(NOQR)](CDEB)	-----	$\left\{\sum_{i=1}^{\infty}[P(CD,E,B)]^i \times T(CDEB)\right\} + [P(F) \times T(CDEFGZ \ldots . R)]$	20.7≅ 21

As can be observed, with the current design of the process and the current process stakeholders and resource allocation, it is estimated that the process takes twenty one working days on average, while authorisation of the process just takes one day (conducted by a section head or a secretary). Taking into the account the weekends, for each integer proportion of five days, two days should be added to the results. Thus, the business process takes twenty seven days in total if it is started on a Monday or a Tuesday, otherwise it takes twenty nine days.

Scenario (8): A business process leading to a payment, with an unlimited number of loop iterations and having a department head or a dean as the authoriser

If the authorisation takes two days, the process will take thirty days if it started on a Monday; otherwise, it will take thirty two days.

Scenario (9): A business process leading to a payment, with an unlimited number of loop iterations and having the rector as the authoriser

If the authorisation takes four days, the process will take thirty one days if it started on a Monday, Tuesday, Wednesday, or Thursday; otherwise, it will take thirty three days.

Scenario (10): A business process leading to a payment, with a limited number of loop iterations and having a secretary or a section head as the authoriser

In scenarios 7 to 9, it is possible that the business process stays in the loop for an infinite number of times. However, according to the business process owners, this is executed either one or two times. Therefore, the following formulae are defined for such specific situations (Table 22).

Table 22 The number of loop executions limited to one or two

Reduction/ Restructuring result	Two loops	Result	One loop	Result
(NPS)(NO)(NOQR)	$\left\{\sum_{i=1}^{2}[p(N,O,QR)]^{i} \times T(NOQR)\right\} + [P(N,O) \times T(NO)] + [P(N,PS) \times T(NPS)]$	4.9	$[P(N,O,QR) \times T(NOQR)] + [P(N,O) \times T(NO)] + [P(N,PS) \times T(NPS)]$	4.9
(CDE)[CDFGZH (IM)(JKM)(JKL)J1(NPS) (NO)(NOQR)] (CDEB)	$\left\{\sum_{i=1}^{2}[p(CD,E,B)]^{i} \times T(CDEB)\right\} + [P(CD,E) \times T(CDE)] + [P(F) \times T(CDEFGZ \ldots .R)]$	17.7≅ 18	$[P(CS,E,B) \times T(CDEB)] + [P(CD,E) \times T(CDE)] + [P(F) \times T(CDEFGZ \ldots R)]$	14.69≅ 15

Considering the weekends, the business process takes between nineteen days and twenty six days, depending on which day of the week it started and how many loops are executed.

Scenario (11): A business process leading to a payment, with a limited number of loop iterations and having a department head or a dean as the authoriser

While authorisation takes two days, the process takes twenty to twenty seven days, depending on which day of the week it started and how many loops are executed.

Scenario (12): A business process leading to a payment, with a limited number of loop iterations and having the rector as the authoriser

While authorisation takes four days, the process takes twenty to twenty eight days, depending on which day of the week it started and how many loops are executed.

Table 23 provides a summary of cycle time estimations in different combinations (scenarios) of business process descriptions, number of loop executions, and authorisers.

Table 23 Summary of cycle time estimation in different combinations of business process descriptions, number of loop executions and authorisers

Business process description	Loop	Authoriser		
		Head of section/ Secretary	Head of Department/Dean	Rector
The invoice may not be paid (including that the problems cannot be fixed)	Unlimited number of loop iterations	25-27	26-28	29
	One or two loop iterations	19-25	19-26	22-27
The invoice will be paid	Unlimited number of loop iterations	27-29	30-32	31-33
	One or two loop iterations	19-26	20-27	20-28

Such an analysis can help managers to make informed decisions in business process management, for example in allocating resources, balancing the flow of activities, delegating tasks to experienced or knowledgeable staff, training staff, automating business process activities or business process parts, and so on.

7.5.3. Measurement at the Business Process Level

For measurement, the stakeholders select ten invoices. All the invoices are paid in the end. Figure 49 and Figure 50 depict cases 1 to 4 and 6 to 10; case 5 is depicted in Figure 52 and Figure 53.

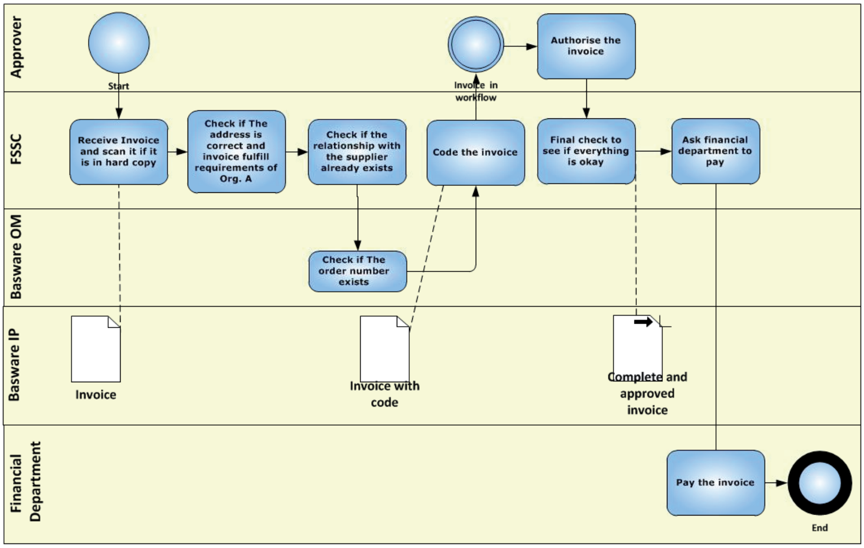

Figure 49 Measured cases business process (1-4 and 6-10)

Using the symbols introduced in Table 18, the measured cases can be represented as Figure 50.

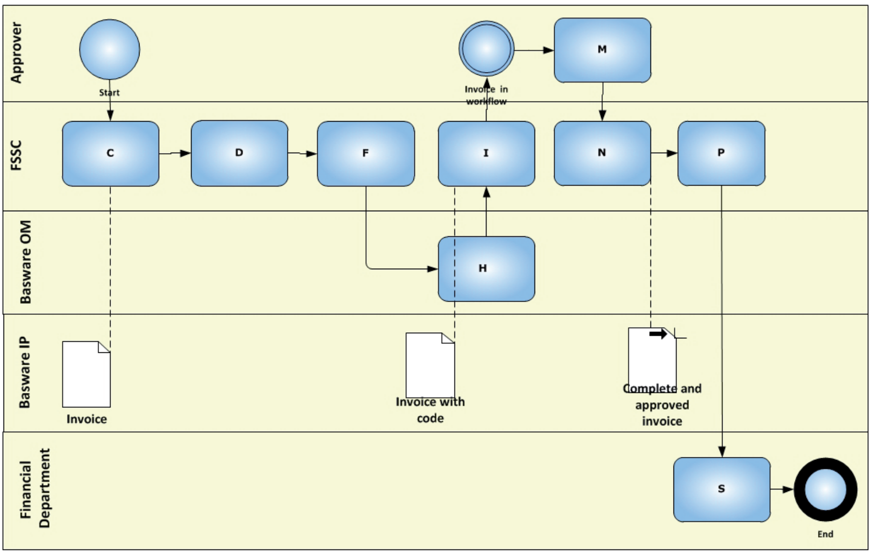

Figure 50 Measured cases business process in symbols (1-4 and 6-10)

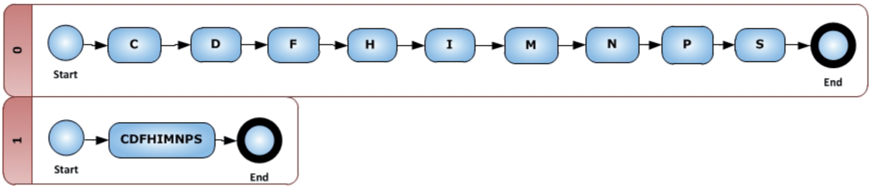

Figure 51 Cases 1-4 and 6-10 reduction

The cycle time of the business process for cases 1-4 and 6-10 can be computed as:

$$T(CDFHIMNPS)= T(C) + T(D) + T(F) + T(H) + T(I) + T(M) + T(N) + T(P) + T(S)$$

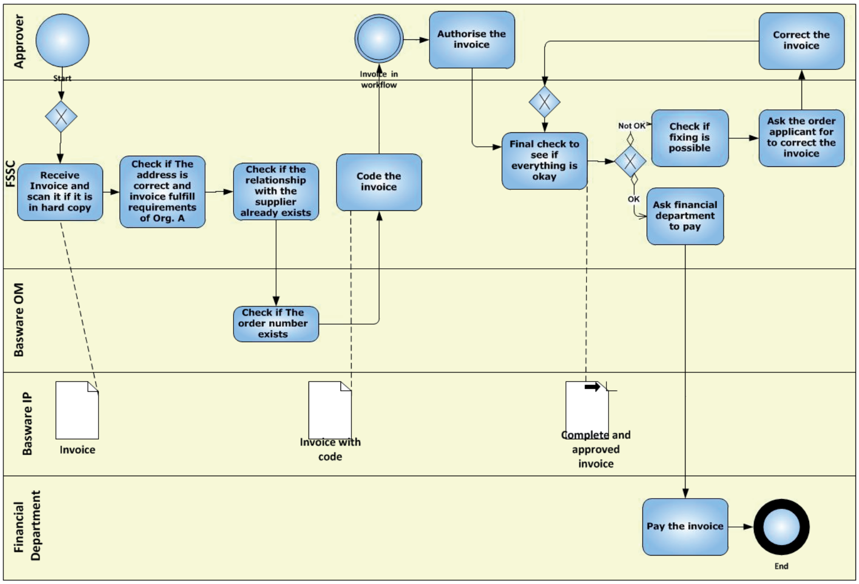

Figure 52 The business process model of case 5

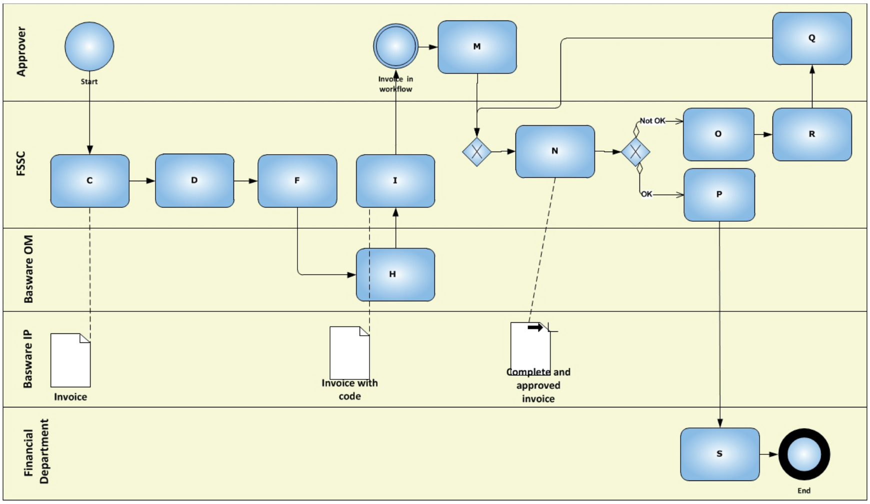

Figure 53 Business process model of case 5 in symbols

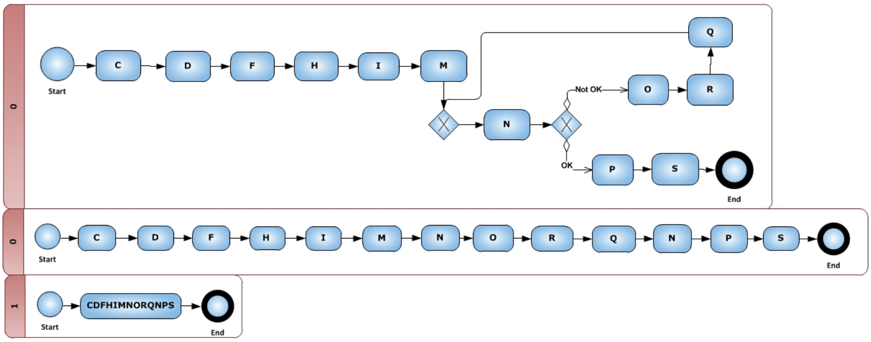

Figure 54 Case 5 reduction

The cycle time of the business process for case 5 can be computed as:

t(cdfhimnps)= t(c) + t(d) + t(f) + t(h) + t(i) + t(m) + 2 * t(n) + t(o) + t(p) + t(r) + t(q) + t(s)

Table 24 presents the cycle time value for each single activity instantiation. The weekend and holiday are already incorporated in the cycle times. For each activity, the average cycle time of the ten instantiations is also provided:

$t_{ave}(a_i) = \frac{\sum_{j=1}^{10} t(a_{ij})}{10}$, where a_i = activity i and a_{ij} = j^{th}instantiation of activity i $(j \in \{1,2,\ldots,10\})$

The total cycle time of each case is measured and an average is calculated.

$$t_{ave}(p) = \frac{\sum_{j=1}^{10} t(p_j)}{10}$$
, where $p_j = j^{th}$ instantiation of the business process $(j \in \{1,2,\ldots,10\})$

The average result is $t_{ave}(p) = 34.8$ which shows a considerable amount of delay (16%). In other words, the process is just 86% time efficient.

The following metric provides a representation of the contribution of each activity in cycle time of the whole business process.

$$t_{\%}(a_i) = \frac{t_{ave}(a_i)}{t_{ave}(P)} \text{ x } 100$$
, where $t_{\%}(a_i)$ = Percentage of the average total time that activity a_i takes.

As depicted in Table 24, the instantiations executed within their defined cycle time are presented in white cells. When an activity instance has a delay, its cycle time is presented in either yellow or red cells, depending on the severity of the delay (i.e. yellow for a mild delay and red for a severe delay).

Activities "Authorise the invoice", "Pay the invoice" and "Code the invoice" with a contribution of 20.40%, 37.07% and 31.03% respectively, contribute the most to the average cycle time and all have considerable amounts of delays in the instances ("Authorise the invoice": 11.9-8.9 days, "Pay the invoice": 7.8, days and "Code the invoice": 6.1 days of delay). One of the main reasons that "Authorise the invoice" takes longer than the target time to be completed is the "Delay Duration" of the activity, due to the fact that the goods are not delivered but the invoice is submitted.

Table 24 The business process cycle time measurement

No	S	Activity (a_i)	Defined Cycle Time	Case Number (j) and the Authoriser 1 Sec.	2 Section Head	3 Dean	4 Sec.	5 Sec.	6 Section Head	7 Section Head	8 Dean	9 Dep. Head	10 Section Head	Average Time $t_{ave}(a_i)$	Average Total Time% $t_{\%}(a_i)$
1	b	Correct the invoice and send it back to FSSC	**3**	0	0	0	0	0	0	0	0	0	0	0	0
2	c	Receive invoice and scan it if it is hardcopy	**3**	0	0	0	0	0	0	0	0	0	0	0	0
3	d	Check if the address is correct and invoice fulfil requirements of Organisation A	**3**	1	1	1	1	1	1	1	1	1	1	1	2.87
4	e	Check if fixing is possible by the supplier	**3**	0	0	0	0	0	0	0	0	0	0	0	0
5	f	Check if the relationship with the supplier already exists	**3**	0	0	0	0	0	0	0	0	0	0	0	0
6	g	Create a new relationship	**2**	0	0	0	0	0	0	0	0	0	0	0	0
7	h	Check if the order number exists	**1**	0	0	0	0	0	0	0	0	0	0	0	0
8	i	Code the invoice	**1**	2	5	0	13	12	4	3	6	6	20	7.1	20.40
9	j	Check if the invoice matches with the purchase and goods' receipt	**1**	0	0	0	0	0	0	0	0	0	0	0	0.00
10	k	Check the invoice and see if a manual correction is possible	**1**	0	0	0	0	0	0	0	0	0	0	0	0.00
11	l	Correct the invoice	**1**	0	0	0	0	0	0	0	0	0	0	0	0.00
12	m	Authorise the invoice	**1/2/4**	1	2	2	7	1	4	16	77	8	11	12.9	37.07
13	n	Final check to see if everything is OK	**1**	1	1	7	1	1+1	1	1	1	1	1	1.7	4.89
14	o	Check if fixing possible	**1**	0	0	0	0	1	0	0	0	0	0	0.1	2.13
15	p	Ask Financial Department to pay the invoice	**1**	1	1	1	1	1	1	1	1	1	1	1	2.87
16	q	Correct the invoice	**1**	0	0	0	0	1	0	0	0	0	0	0.1	2.13
17	r	Ask the order applicant to correct the invoice	**1**	0	0	0	0	1	0	0	0	0	0	0.1	2.13
19	s	Pay the invoice	**3**	1	4	4	13	24	1	1	1	58	1	10.8	31.03
20	$T(P_j)$	Total Cycle Time	**30**	7	14	15	36	44	12	23	87	75	35	34.8	$t_{ave}(p)$

7.5.4. Suggestions for Improving the Business Process

The following recommendations are suggested to reduce the delay in the execution of the business process:

- In the current situation, fifty per cent of the invoices are either sent back to the suppliers for correction to meet the requirements of Organisation A or end up with no payment, in which case the initialisation of another business process for the purpose of correction is the result. Each correction creates up to twelve days of delay, and with the possibility of loops and iterations, a longer delay might occur. The following is suggested to overcome this problem:
    - Have a standard invoice designed on the basis of the requirements of Organisation A, accompanied with a checklist to be filled in by the supplier. Electronic submission of the invoices can also be a solution. In this case, an integrated portal is needed, through which the supplier and the order applicant can sign in, submit their invoice, according to Organisation A's rules. Tracking the payment should be considered to also foster fast communication and to identify the need for corrections when needed. This may be a solution for small or medium enterprises for which Organisation A is a very important customer.
    - Inform or educate suppliers and order applicants about the requirements and the role of having quality information in the invoices for a timely payment.
- At the moment, eighty five per cent of the invoices are without a reference code. As a consequence, two activities, "coding the invoice" and "correcting the invoice," have to be executed. As can be observed, both activities have the tendency of being executed with a huge amount of delay. To overcome this problem, the following is suggested:
    - Increase the number of orders with a reference code. In doing so, the order applicants should be informed about the necessity of submitting a coded invoice. The Financial Department should ensure that order applicants are aware of the procedure and the way it works.
    - As an extension of electronic submission of an invoice, integrate invoice submission and PM (purchase management) order creation to include frequent reminders to the order applicant about the need for an order number during submission.
    - Introduce a mechanism that sends reminders to prevent delays in authorisation activities.
- The business process is complex, with nine decision points of which a few may create loops. In addition, there is a chance that after spending a huge amount of

7

time processing, an invoice ends up not being paid due to poor quality of information in the invoices.

- The following are a few examples:
  - As mentioned before, there is a fifty per cent chance that an invoice does not meet Organisation A's requirements.
  - There is an eighty per cent chance that an invoice does not match with the purchase and goods receipt. For the non-matching invoices, there is a sixty per cent chance that manual correction is not possible. This creates delay, as there is a need for authorising the invoices and to perform correction.
  - In the end, ten per cent of the invoices might still be problematic and some may not have been paid. This creates a huge cost for Organisation A, at least in terms of time spent by the staff and dissatisfaction of suppliers.

Here are some suggestions to overcome these problems:

- Position critical decision points in the beginning of the process, rather than to have them considered at the last moment.
- Create parallel paths in situations where there is no need to execute tasks in a specific order.
- Merge decision points as much as possible. Therefore, the business process should be redesigned, checklists should be created, and staff should be trained. Scenarios and games can be deployed for (a) designing new processes with the cooperation of some experienced financial staff, order applicants, and suppliers, (b) training the process executers.
- In case of a portal for submitting the invoices (integrated with creating a PM order), there should also be an automated means for early "checking if an invoice matches with the purchase and goods receipt" at the same time. This would reduce the need for manual correction and enable tracking of the corrections.
- As mentioned before, ten per cent of the invoices might still be wrong and need corrections. These corrections would not be necessary if the portal and its fields are designed appropriately and are mistake-proof.

7.6. Evaluation of the Results

The measures developed in section 6.4.2 for the evaluation are revisited in this section, measuring (a) how effective is the business process integrating meta-model to specify the business process model, (b) how effective is the approach to computing quality of the business process concepts, and (c) how effective is the approach to computing quality of the business process. Implemented in this case study, three topics are evaluated in the following subsections: (a) effectiveness of the business process integrating meta-model, (b) quality computation of business process concepts, and (c) quality computation of business process.

7.6.1. Evaluation of BPIMM

The goal is to provide a suitable answer to the question: *Can the business process integrating meta-model effectively specify the business process model in this case study?*

In this context, BPMN is deployed for representing the business process. Mapping the concepts and relationships in the model onto the business process integrating meta-model's concepts and relationships is a concern. The evaluation measure developed in section 6.4.2 is used, showing the percentage of concepts and relationships of the model that can be mapped onto the concepts and relationships in the integrating meta-model:

$$P_M = \frac{N_f}{N_C + N_r} \times 100$$

In the business process, the following concepts are identified: lane, start event, end event, intermediate event, exclusive event, gateway, atomic activity, data object output, association, sequence flow, and conditional sequence. These concepts are covered by the concepts introduced in the integrating meta-model (BPIMM). Moreover, the relationships between these concepts are also covered by the relationships defined in BPIMM. As a result, a mapping of one hundred per cent onto BPIMM demonstrates that the meta-model can provide a representation of the business process model.

7.6.2. Evaluation of BPC-QC

Implemented in this case study, an evaluation of (a) BPC-QEF and algorithm, (b) quality factors and (c) quality metrics is conducted via answering the questions defined in the measurement model introduced in section 6.4.2.

a) *<u>Business Process Concept Quality Evaluation Framework (BPC-QEF) and algorithm:</u>*

- <u>Are the conceptual model and method steps sufficient and effective in identification of concepts, factors and metrics?</u>

The conceptual model and method steps are sufficient and effective in identification of the concepts, factors and metrics for quality computation. During the design workshop, the researcher and stakeholders follow the steps and the model to identify concepts and factors and metrics given the quality requirements of the stakeholders. As a result, there is no need for modification of the BPC-QEF and algorithm.

b) *<u>Quality factors</u>*

- <u>Are the definitions of quality factors correct?</u>

During the design workshops, quality factors are explained and their definitions are reviewed. The definitions are found to be clear and consequently there is no need for modification.

- Do they suffice?

As mentioned earlier the requirements of (a) "The quality of information of the invoices improved", and (b) "The number of invoices with an order number should increase" are outside the scope of this thesis. However, responding to the stakeholders' request a new quality factor is introduced specifically for this case study without the need for adding to the existing quality factors.

c) *Quality metrics*

- Are the definitions of the metrics correct?

The stakeholders also define "Failure in coding invoices should be reduced" as a requirement relating failures in coding to the total number of coding. The initial failure frequency metric defined in the thesis is time-based, mandating a new metric for this purpose.

- Do they suffice?

For the two aforementioned quality requirements out of the thesis scope, two new quality metrics are introduced specifically for this case study without the need for adding to the existing quality dimensions.

7.6.3. Evaluation of BP-QC

An evaluation of (a) BP-CQCF and algorithm, (b) business process patterns and (c) computational formulae is conducted for the questions defined in the measurement model introduced in section 6.4.2.

a) *Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm*

- Are the conceptual model and the method steps sufficient and effective for the purpose of computation?

BP-CQCF and algorithm are followed for the purpose of computation. The conceptual model and method steps are found sufficient and effective in conducting the computation. As a result, there is no need for modification of the BPC-QEF and algorithm.

b) *Business process patterns*

- Are the definitions of the business process patterns correct?

During the implementation, business process patterns are reviewed. The definitions are considered to be correct and consequently there is no need for modification.

- Do they suffice?

With regards to the structure of the business process model, the business process patterns are sufficient for decomposing the business process. As a result, there is no need for modification.

- Do all of the business process parts map 1-1 onto the proposed well-structured patterns?

The business process consists of some parts with embedded patterns, which makes a 1-1 mapping onto the proposed well-structured patterns impossible. As a result, the process is restructured to make the mapping possible and consequently conducting the computation. The new parts are equivalent to the original parts. Where needed, new probabilities are calculated.

c) Computational formulae

- Are the computational formulae correct?

The proposed formulae for time computation are considered to be correct. As a result, there is no need for changing the definition of the computational formulae.

- Do they suffice?

The set of formulae is sufficient for computing time in this case study. There is no need for adding new formulae for computing time.

7.7. Evaluation of the Approach by Individual Stakeholders

In this section, the measures on utility evaluation (section 6.4.2) are revisited, capturing the views of stakeholders on the applicability, usability, and usefulness of the approach. To this end, the researcher conducts semi-structured interviews with the business process stakeholders to evaluate the utility of the case study. Opinions from technology-oriented and management-oriented stakeholders are captured. Together, the stakeholders have more than 48 years of experience and work for more than 34 years in Organisation A

The set of codes introduced in Section 6.4.3 acts as the basis for data analysis of the interviews. The three sub-codes “Positive” (+), “Negative” (-), and “In Between” (+/-) represents the interviewees’ opinions. Table 25 provides an overview of the interviewees’ opinions for different codes.

Table 25 Overview of the interviewees' opinions on different evaluation codes

		Interviewees	
		A1	A2
Codes	Relevancy of quality factors and dimensions for the business process	+/-	+/-
	Overall relevancy of quality factors and dimensions	+/-	+
	Adequacy of quality factors and dimensions	+	+
	Ease of use of BPC-QEF and algorithm	+	+
	Ease of learning BPC-QEF and algorithm	+	+
	Scalability of BPC-QEF and algorithm	+	N/A
	Coherence of BPC-QEF and algorithm	+	+
	Reliability of the measurement results	+	+
	Reliability of the estimation results	+	+
	Overall usefulness of the approach	+	+
	Improvement with respect to the current situation	+	+
	Overall usability of the approach	+	+
	Support required for implementation	+	+

A factual report is provided from the interview data analysed by coding the data through the use of the ATLAS.ti 7.0 tool. Each statement in the report is accompanied by a closed parenthesis following this format: [#code of the interviewee: #Text Fragment Number in the transcript (T)] supporting the statement. Quotations from different stakeholders are separated by a "/" sign.

The outcome of the analysis with respect to the evaluation measures discusses:

- Relevancy and adequacy of the quality dimensions and factors.

- Ease of use, ease of learning, scalability and coherence of BPC-QEF and algorithm.
- Reliability of the measurement and estimation results.
- Overall usefulness of the approach.
- Improvement with respect to the current situation.
- Usability and support required for the implementation.

Each following sub-section elaborates on one of the aforementioned measures.

7.7.1. Relevancy and Adequacy of the Quality Dimensions and Factors

Relevancy: The objective is to evaluate the relevancy of the quality dimensions and factors introduced in Section 4.3 for the investigated business process as well as the overall relevancy of the dimensions and factors. The overall relevancy of quality dimensions and factors is reviewed during the interviews and is acknowledged by the interviewees [A1:T9/A2:T7]. Specifically, the relevancy of authority, performance, efficiency, recoverability and reliability dimensions is highlighted [A2:T12,T13]. For the business process studied, all dimensions are considered relevant [A2:T7]. However, not all of the aspects of quality are weak points in the business process; Therefore, it is effective to measure all the aspects [A2:T7]. Specifically, relevancy of the cycle time and efficiency dimension is mentioned [A1:T8].

Adequacy: The objective is to evaluate the adequacy of the quality dimensions and factors introduced in Section 4.3, to examine whether a quality factor or dimension is missing from the list. The adequacy of the proposed dimensions and factors are reviewed during the interviews and it is mentioned that the list covers fully the need of the Financial Department of Organisation A [A1:T10/A2:T8].

7

7.7.2. Ease of Use, Ease of learning, Scalability and Coherence of BPC-QEF and Algorithm

The objective is to evaluate the ease of use, ease of learning, scalability, and coherence of BPC-QEF introduced in Section 4.2.

Ease of use: It is asserted that the approach for realising quality factors and metrics is easy to use [A2:T17/A1:T11]. It is maintained that, as the process is known to the department and as the department is working on its improvement, the approach makes the specification of quality factors and metrics more understandable and clear [A2:T17]. Moreover, it is mentioned that how using the same tool for visualisation can foster faster specification of the quality factors and dimensions [A2:T6].

Ease of learning: It is affirmed that the framework and algorithm are clear [A1:T12/A2:T5,T14] in a way that everybody can understand and thus use them [A1/T12].

Scalability: It is asserted that the framework and algorithm can be employed for capturing quality requirements and factors for other business processes and even bigger ones [A1:T14].

Coherence: The interviewees indicate that the approach in capturing quality factors and metrics is coherent and systematic [A1:13/A2:18].

7.7.3. Reliability of the Measurement and Estimation Results

The reliability of the measurement and estimation results is reviewed during the interviews. It is stated that the results of both measurement [A1:T15/A2:T20,T24] and estimation are reliable [A1:T16/A2:T23,T24]. It is supported that the results are according to the expectation of the higher-ranked manager, but they could not be verified by independent computation [A1:T15,T16].

7.7.4. Overall Usefulness of the Approach

The overall usefulness of the approach is reviewed during the interviews. The usefulness of the approach is confirmed [A1:T19,T20/A2:T32,T33,T34,T35,T36,T38,T39,T42,T45]. It is also acknowledged that the approach could be useful for other departments within the organisation [A1:T20/A2:T32,T33,T34,T36,T42]. Stakeholders state that the approach developed in this thesis is relevant and appropriate for other fields of interests and domains such as top management [A2:T32], human resource [A1:T20/A2:T36], facility management [A2:T34,T36] and ICT departments [A2:T34,T36].

The bottom-up quality evaluation and its benefits to the organisation are highlighted as the generation and flow of information is currently top-down [A2:T34]. It is affirmed that the case study provides a new viewpoint and possibilities to follow in future [A2:T35]. It is asserted that the approach helps to save energy in the process and take the capacity and make other things better and cheaper [A2:T38]. Moreover, it is highlighted that through implementing the approach (a) one can get useful insights about the process [A2:T45], (b) the source of the problem can be pinpointed [A2:T39], (c) the flow of work would be smoother [A2:T39], (d) processes would be improved and more efficient [A2:T39], and finally (e) stakeholders would benefit from it [A2:T39].

7.7.5. Improvement with Respect to the Current Situation

The possible improvement achieved via case study implementation is reviewed during the interviews. It is acknowledged that the approach pinpoints a few problems that were unknown [A2:T30]. It is confirmed the approach highlights the importance of business process design for the performance of the business process [A1: T17,T24/A2:T9,T25,T30]; For example, one of the suggestions for improvement is having the decision points early instead of late in the business process; this will help the process to take less time as recoveries from potential failures would be quicker [A1: T17,T24/A2:T9,T25,T30]. Moreover, it is affirmed that the case study has brought back the attention to the quality of the invoices by suppliers and the need for communicating this to the supplier [A2:T30].

7.7.6. Usability and Support Required for Implementation

The usability and support required for implementation are stated in the interviews. It becomes apparent that the implementation of the proposition is a concern [A2:T14,T41]. The required supports for the implementation of the approach are discussed. The need for a mechanism enabling automatic evaluation of the quality instead of performing evaluations manually is highlighted [A2:T16]. It is maintained that for implementation, the approach needs a formal design and template so that one can extract data from the database [A1:T21/A2:T16,T41], and conduct the measurement automatically [A2:T16,T41]. It is suggested that a quality measurement implemented in the software such ERP systems embedding a measurement tool is a big immediate step for implementation [A2:T43,T41]. Moreover, the necessity of investment in services that are involved in the process's information is highlighted [A2:T43]. Besides, the need for flexibility of the evaluation system due to changes in business processes is recognised [A2:T41].

The support of management in implementing the approach is highlighted [A2:T42]. As the implementation is time-consuming for all the business processes in the organisation [A2:T43], the manager should understand the approach and its benefits and be willing to implement it [A2:T42]. It is highlighted that due to the usual short-term appointments of the managers [in this organisation], having their agreements on implementing such approaches is challenging [A2:T42].

7.7.7. Summary of the Evaluation by the Stakeholders

Revisiting the evaluation measures introduced earlier in this section, a summary of the evaluation by the stakeholders is provided.

- **Relevancy and Adequacy of the Quality Dimensions and Factors:**

Relevancy: The overall relevancy of the quality dimensions and factors as well as the relevancy for the specific business process are acknowledged by the interviewees. Specifically, the relevancy of the dimensions authority, performance, efficiency, recoverability, and reliability is highlighted.

Adequacy: The adequacy of the proposed dimensions and factors are reviewed during the interviews and it is mentioned that they fully cover the requirements of the stakeholders.

- **Ease of Use, Ease of Learning, Scalability, and Coherence of BPC-QEF and Algorithm:**

Ease of use: It is asserted that the approach for realising quality factors and metrics is easy to use.

Ease of learning: It is affirmed by the interviewees that the framework and algorithm are clear in a way that everybody can understand and thus use them.

Scalability: It is asserted that the framework and algorithm can be employed for capturing quality requirements and factors for other business processes and even bigger ones.

Coherence: The interviewees find the BPC-QEF coherent.

- **Reliability of the Measurement and Estimation Results:**

It is acknowledged that the results of both measurement and estimation are reliable.

- **Overall Usefulness of the Approach:**

The usefulness of the approach is confirmed. It is also acknowledged that the approach could be useful for other departments within the organisation, such as top management, human resources, facility management, and IT departments. The bottom-up quality evaluation and its benefits to the organisation are highlighted. Moreover, it is asserted that through implementing the approach (a) one can get useful insights about the process, (b) the source of the problem can be pinpointed, (c) the flow of work would be smoother, (d) processes would be improved and more efficient, and finally (e) stakeholders would benefit from it.

- **Improvement with Respect to the Current Situation:**

It is acknowledged that the approach pinpoints a few problems that were unknown. It is confirmed the approach highlights the importance of business process design for the performance of the business process. Moreover, it is maintained that the case study has brought back the attention to the quality of the invoices by suppliers and the need for communicating this to the supplier.

- **Usability and Support Required for the Implementation:**

It becomes apparent that the implementation of the proposition is a concern. The need for a mechanism enabling automatic evaluation of the quality instead of performing evaluations manually is highlighted which demands for a formal design and template so one can extract data from the database. It is suggested that a quality measurement implemented in software, such as ERP systems embedding a measurement tool, is a big immediate step for implementation. Besides, the need for flexibility of the evaluation system due to changes in business processes is recognised. Finally, the support of management in implementing the approach is highlighted.

7.8. Chapter Summary

This chapter elaborates a case study conducted for a real-life business process from the Financial Department of Organisation A. The context, the stakeholders, and their requirements are described. On the basis of Organisation A's requirements, a complete case study is conducted, including (a) the business process integrating meta-model evaluation, (b) requirements specification, (c) measurement at the concept level, (d) cycle time estimation at the business process level, and (e) cycle time measurement at the business process level. A set of suggestions is provided to improve the quality of the business process. An evaluation of the findings is provided on effectiveness, based on the result acquired, and on utility, based on the feedback received from the stakeholders via conducting interviews

Chapter 8. Case Study Organisation B

Nothing has such power to broaden the mind
as the ability to investigate systematically and truly
all that comes under thy observation in life.
-Marcus Aurelius

8.1. Introduction

This chapter elaborates on a case study conducted for Organisation B (a global financial institution) for one specific business process.

This chapter is organised as follows. Section 8.2 describes the context, stakeholders and their requirements. Section 8.3 provides a mapping of the business process onto BPIMM. Section 8.4 elaborates on the business process estimation and a bottleneck analysis, and Section 8.5 presents an effectiveness evaluation of the findings. Section 8.6 describes an evaluation on utility, and Section 8.7 provides a summary of the chapter.

8.2. Context, Stakeholders, and Environment

In this thesis, the case study is conducted in the context of Organisation B, in the business line of retail banking. Organisation B is a global financial institution of Dutch origin, currently offering banking, investments, life insurance, and retirement services. Its strategic aim is to be a strong and predominantly European bank for its customers.

Stakeholders from Organisation B with technology orientation are involved in the evaluation of the utility of the artefact. By the time of interview, stakeholders had five years and four months of experience. The roles of the stakeholders are shown in Table 26.

Table 26 Organisation B stakeholders involved in the evaluation as interviewees

ID	Role of the interviewee	Years of experience	Years of experience in the organisation	Interview conduct
B1	Lean Six Sigma Blackbelt	1.5	1.5	One-to-One
B2	Lean Six Sigma Blackbelt	1.3	1.3	One-to-One
B3	Lean Six Sigma Blackbelt	2.5	2.5	One-to-One

The stakeholders are all employed by the department of Lean Six-Sigma and involved in projects for new implementations or improving current situations.

One of the objectives of Organisation B is to have high-quality business processes, specifically efficient in time to gain higher customer satisfaction. Given the research deliverables as well as the priorities of Organisation B, a business process from one of the current design projects of the bank is selected for the case study. This business process has not yet been implemented. However, to be able to plan resources, the organisation is interested to know about the total time the process will take in total. Applying one of the thesis contributions (i.e., BP-CQCF) to this particular case study helps management to have a data-driven estimation of the time that the business process will take. The cycle time estimation of the business process is in the scope of the evaluation.

The first step is to agree on the representation of the business process, namely the business process model. The first version of the business process description is provided by the stakeholders. The language does not have a formal specification, but it is used throughout Organisation B. A simplified version of the business process model is provided in Figure 55, in which, where applicable, a series of sequential activities is replaced by one activity for the matter of simplicity. The names of activities are not revealed for reasons of confidentiality.

The business process model is translated into BPMN as a standard and mainstream business process modelling language, to provide a formal representation of the business process in terms of semantics and syntax. Ambiguities are discussed and resolved with the stakeholders, resulting in an agreed definition of the business process as depicted in Figure 56.

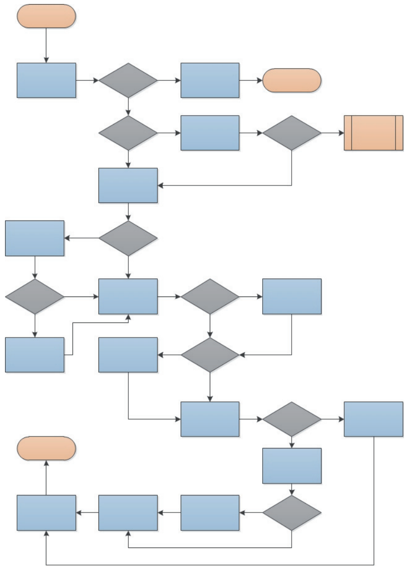

Figure 55 Simplified version of the business process modelled by the stakeholders

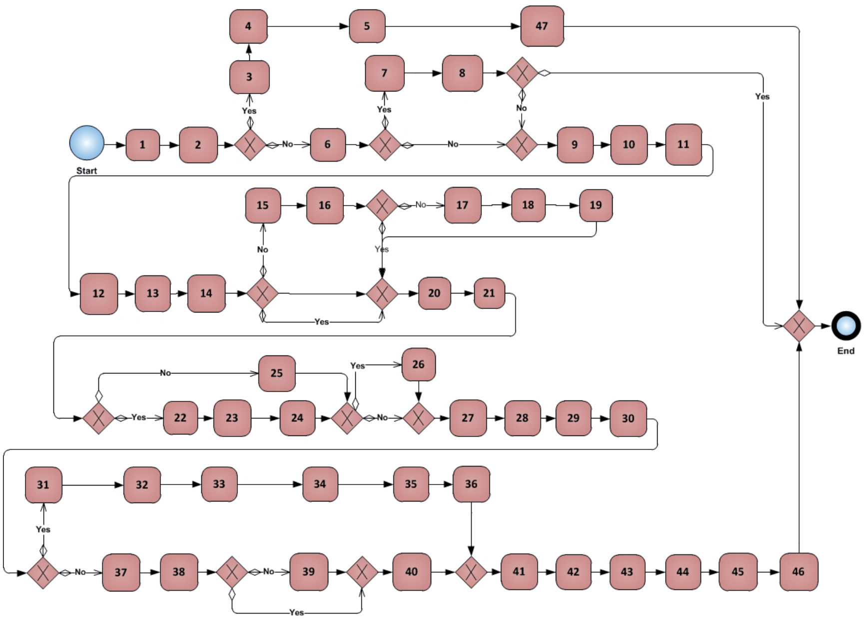

Figure 56 Business process model in BPMN

BPMN is used throughout the case study for the presentation of the business process and for estimation purposes. Each activity is assigned a number for reference purposes.

8.3. The Integrating Meta-Model Specification of the Business Process

In the business process model depicted in Figure 56, the following concepts are identified: lane, start event, end event, exclusive event, gateway, atomic activity, sequence flow, and conditional sequence. These concepts and their relationships can be mapped 1-1 with the concepts and relationships identified in the integrating meta-model BPIMM.

8.4. Quality Computation of the Business Process

8.4.1. Computation

In line with the approach of BP-CQCF (Business Process Compositional Quality Computation Framework) introduced in Section 4.2, the cycle time of the business process is estimated from the estimated cycle time values of all constituent activities and their estimated probabilities.

The following terminology is deployed in this case study:

- **Execution time:** The duration of the time spent on execution of the activity (i.e., workload in the Organisation B terminology).
- **Delay duration:** Waiting time, that is the time between the executions of one activity and its succeeding activity, (termed throughput time in Organisation B) which entails: Queue duration, Synchronisation duration, and Set up duration. As a result, in an activity preceded by a joint, several durations of synchronisation are considered in the calculation.
- **Cycle time Duration:** The total time an activity takes, which is the sum of Execution time and Delay duration.

The stakeholders provide the execution time, delay duration and probability of each outgoing branch.

As mentioned above, Organisation B distinguishes two kinds of time in their calculation. One is the actual execution time and the other is the delay duration. Delay duration is the time allocated to each of the arrows between activities. Figure 57 presents a small example. As can be observed, two different routes can be taken to reach activity 40.

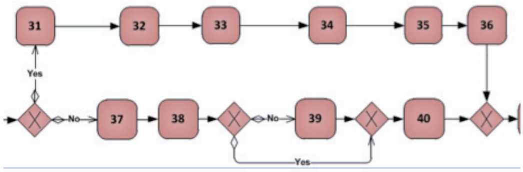

Figure 57 Example of different delay durations incorporated into the cycle time of activity 40

Therefore, two different delay durations can be allocated to activity 40, each with different probabilities. As a result, in measuring the cycle time of activity 40, these different probabilities are incorporated. The following formula is defined for this specific purpose:

$T(A) = DD(A) + PD(A)$	A = activity T(A) = cycle Time duration of an activity DD(A) =Delay Duration of an activity PD(A)= Process Duration of an activity
$DD(A) = \sum_{i=1}^{n} P_i \times RD_i(A)$ $\sum_{i=1}^{n} P_i = 1$	i = number of a route P_i = Probability of taking route I $RD_i(A)$= Route i Duration of activity A

The formula is defined for this specific situation extending BP-CQCF for this specific case.

The cycle times of activities 20, 27, 40, and 41 are calculated through implementation of the above formula, as each route leading to these activities takes a different amount of time. Delay duration is based on the provided data, and the cycle time of each activity is computed as the sum of the execution time and the delay duration (Table 27).

8

Table 27 Activity cycle time computation (minutes) and their probabilities

Activity	Execution time	Delay Duration	Cycle time	Probability
1	35	960	995	1
2	1	0	1	1
3	10	480	490	0.05
4	30	0	30	0.05
5	5	6720	6725	0.05

Activity	Execution time	Delay Duration			Cycle time	Probability
6	1	0			1	0.95
7	7	0			7	0.02
8	3	5760			5763	0.02
9	30	0			30	0.95
10	10	6720			6730	0.05
11	15	480			495	0.95
12	8	0			8	0.95
13	15	0			15	0.95
14	3	4800			4803	0.95
15	5	0			5	0.35
16	1	2400			2401	0.35
17	240	0			240	0.75
18	5	4800			9605	0.75
19	240	480			720	0.75
20	10	9600	P=0.75*0.35=0.2625	2520	2530	1
		0	P=0.65			
		0	P=0.25*0.35=0.1875			
21	15	0			15	1
22	5	0			5	0.1
23	1	0			1	0.1
24	20	9600			9620	0.1
25	1	0			1	0.9
26	10	0			10	0.35
27	30	4800	P=0.35	1680	1710	1
		0	P=0.65			
28	1	2400			2401	1
29	15	4800			4815	1
30	2	0			2	1
31	3	480			483	0.05

<table>
<tr><th>Activity</th><th>Execution time</th><th colspan="3">Delay Duration</th><th>Cycle time</th><th>Probability</th></tr>
<tr><td>32</td><td>5</td><td colspan="3">0</td><td>5</td><td>0.05</td></tr>
<tr><td>33</td><td>30</td><td colspan="3">960</td><td>990</td><td>0.05</td></tr>
<tr><td>34</td><td>8</td><td colspan="3">0</td><td>8</td><td>0.05</td></tr>
<tr><td>35</td><td>1</td><td colspan="3">9600</td><td>9601</td><td>0.05</td></tr>
<tr><td>36</td><td>1</td><td colspan="3">9600</td><td>9601</td><td>0.05</td></tr>
<tr><td>37</td><td>480</td><td colspan="3">4800</td><td>5280</td><td>0.95</td></tr>
<tr><td>38</td><td>1</td><td colspan="3">480</td><td>481</td><td>0.95</td></tr>
<tr><td>39</td><td>3</td><td colspan="3">0</td><td>3</td><td>0.95</td></tr>
<tr><td rowspan="2">40</td><td rowspan="2">5</td><td>1440</td><td>P=0.95</td><td rowspan="2">2160</td><td rowspan="2">2165</td><td rowspan="2">0.95</td></tr>
<tr><td>15840</td><td>P=0.05</td></tr>
<tr><td rowspan="2">41</td><td rowspan="2">1</td><td>14400</td><td>P=0.95</td><td rowspan="2">14016</td><td rowspan="2">14017</td><td rowspan="2">1</td></tr>
<tr><td>6720</td><td>P=0.05</td></tr>
<tr><td>42</td><td>15</td><td colspan="3">480</td><td>495</td><td>1</td></tr>
<tr><td>43</td><td>1</td><td colspan="3">7200</td><td>7201</td><td>1</td></tr>
<tr><td>44</td><td>15</td><td colspan="3">0</td><td>15</td><td>1</td></tr>
<tr><td>45</td><td>15</td><td colspan="3">19200</td><td>19215</td><td>1</td></tr>
<tr><td>46</td><td>30</td><td colspan="3">6720</td><td>6750</td><td>1</td></tr>
<tr><td>47</td><td>0</td><td colspan="3">960</td><td>960</td><td>0.01</td></tr>
</table>

BP-CQCF distinguishes different iterative phases: decomposition, computation, and aggregation. In the first phase, the business process is decomposed into different parts according to the patterns introduced in Section 5.3. Each part is reduced into a single activity and computed. The result of reducing each set of activities is represented as another activity, labelled by a unique letter. There is no specific rule followed in labelling. The end result is one single activity as illustrated in Figure 58 and Figure 59.

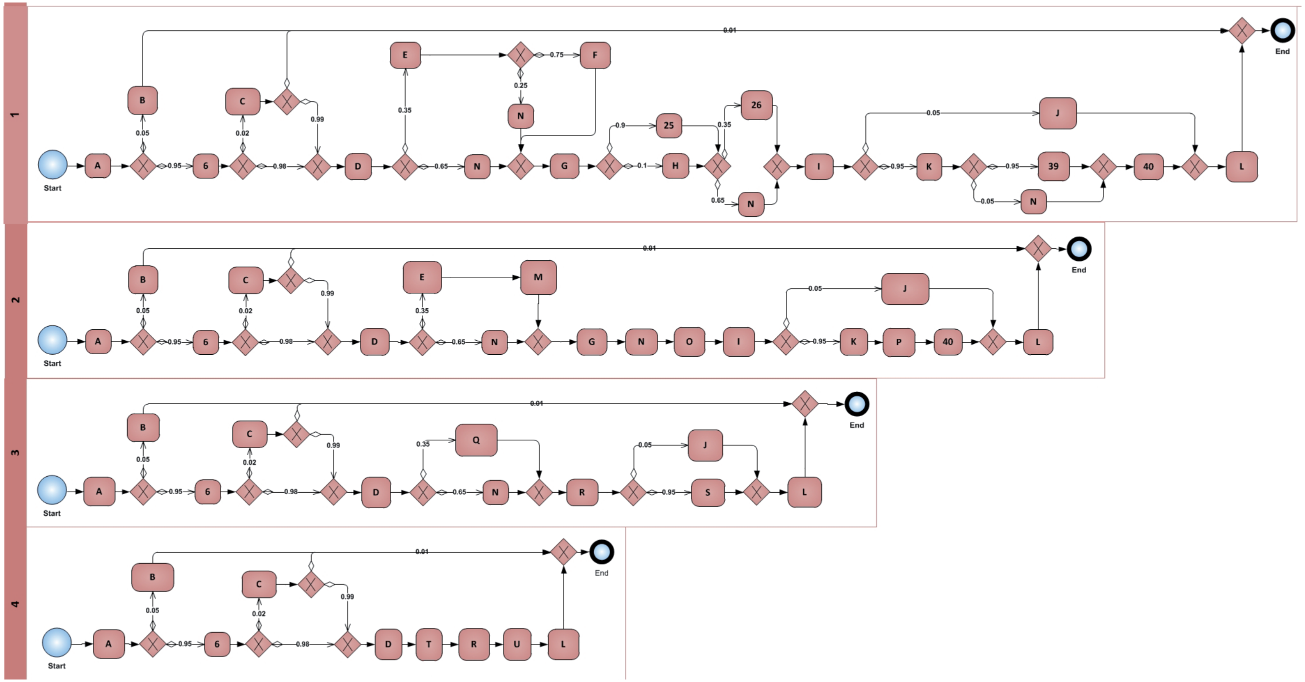

Figure 58 Stepwise reduction for estimation (Steps 1-4)

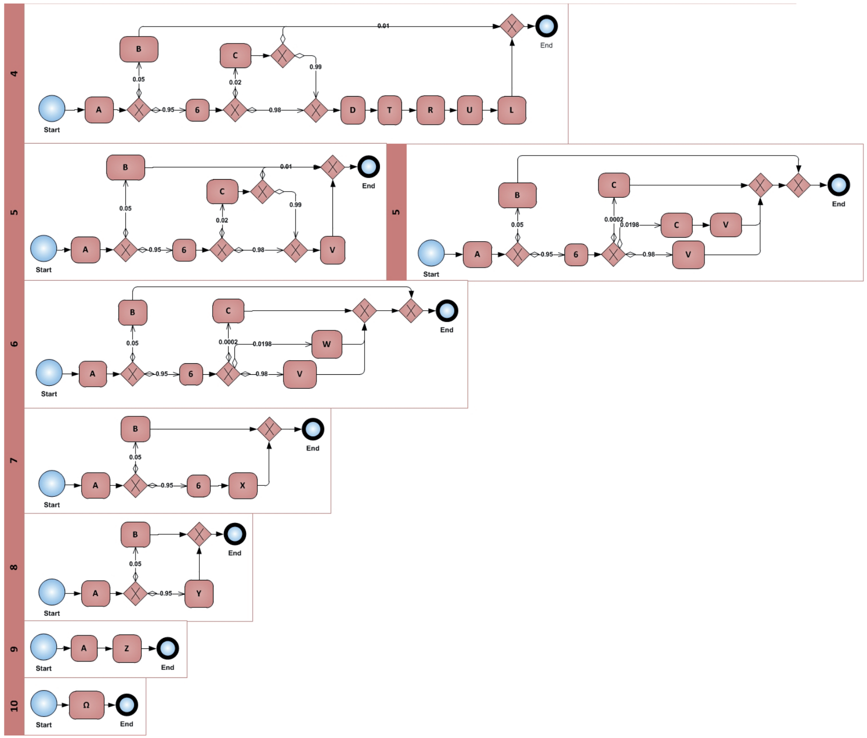

Figure 59 Stepwise reduction for estimation (Step 4-10)

The business process consists of a part with embedded patterns (step 5 of the reduction). Computation of this part is challenging, as BP-QC offers no formal solution for embedded patterns. The solution chosen to overcome this challenge is to introduce a number of sequence flows to restructure this part of the business process to be equivalent to the original part. The business process with the new structure is provided on the right-hand side in the same row as the original structure (Figure 59). For the restructured part, new probabilities are calculated.

Table 28 provides the formulae for computation of the quality of the activities resulting from each reduction stage.

Table 28 Business process cycle time estimation

Step	Reduction result	Symbol	Probability	Reduction Formula	Result
1	1-2	A	0.95	T(1)+T(2)	996
	3-5,47	B	0.05	T(3)+T(4)+T(5)+T(47)	8205
	7-8	C	0.02 Step 1-4 0.002 Step 5	T(7)+T(8)	5770
	9-14	D	0.95	T(9)+T(10)+T(11)+T(12)+T(13)+T(14)	12078
	15-16	E	0.35	T(15)+T(16)	2406
	17-19	F	0.75	T(17)+T(18)+T(19)	10565
	20-21	G	0.95	T(20)+T(21)	2545
	22-24	H	0.1	T(22)+T(23)+T(24)	9626
	27-30	I	0.95	T(27)+T(28)+T(29)+T(30)	8928
	31-36	J	0.05	T(31)+T(32)+T(33)+T(34)+T(35)+T(36)	20688
	37-38	K	0.35	T(37)+T(38)	5761
	41-46	L	0.95	T(41)+T(42)+T(43)+T(44)+T(45)+T(46)	47693
2	N(17-19)	M	0.35	P(F)*T(F)	7923.8
	22-24,25	N	0.95	P(H)*T(H)+P(25)*T(25)	963.5
	N26	O	0.95	P(26)*T(26)	3.5
	N39	P	0.95	P(39)*T(39)	2.9

Step	Reduction result	Symbol	Probability	Reduction Formula	Result
3	15-16,N(17-19)	Q	0.35	T(E)+T(M)	10329.8
	20-21,22-24,25,N26,27-30	R	0.95	T(G)+T(N)+T(O)+T(I)	12440
	37-38,N39,40	S	0.95	T(K)+T(P)+T(40)	7928.9
4	N[15-16,N(17-19)]	T	0.35	P[Q)]*T[Q]	3615.4
	31-36,37-38,N39,40	U	0.95	P(J)*T(J)+P(S)*T(S)	8566.8
5	9-14,N[15-16,N(17-19)],20-21,22-25,N26,27-30,37-38,N39,40,31-36,41-46	V	0.98	T(D)+ T[T]+T(R)+T(U)+T(L)	84393.2
6	7-8,9-14,N[15-16,N(17-19)],20-21,22-25,N26,27-30,37-38N39,40,31-36,41-46	W	0.0198	T(C)+T(V)	90163.2
7	#7-8,9-14,N[15-16,N(17-19)],20-21,22-25,N26,27-30,37-38N39,40,31-36,41-46	X	0.95	P(C)*T(C)+P(W)*P(W)+P(V)*T(V)	84502.1

Step	Reduction result	Symbol	Probability	Reduction Formula	Result
8	6,#7-8,9-14,N[15-16,N(17-19)],20-21,22-25,N26,27-30,37-38N39,40,31-36,41-46	Y	0.95	T(6)+T(X)	84503.1
9	3-5,47,6,#7-8,9-14,N[15-16,N(17-19)],20-21,22-25,N26,27-30,37-38N39,40,31-36,41-46	Z	1	P(B)*T(B)+P(Y)*T(Y)	80688.2
10	1-2,3-5,47,6,#7-8,9-14,N[15-16,N(17-19)],20-21,22-25,N26,27-30,37-38N39,40,31-36,41-46	Ω	1	T(A)+T(Z)	81684.2

As demonstrated, estimation of the requirements' fulfilment by the business process is based on the results of its constituent activities. Moreover, the estimation is carried out in a systematic and repeatable manner to provide a quantitative estimation. In the current design of the process and with the current process stakeholders and resource allocation, it is estimated that the process will take 81684 minutes (approximately equal to 1361 hours or 8.5 months) on average[1]. These results indicate differences between the current situation, the estimated value, and the target quality value. Based on the existing differences, the organisation can change the way it achieves its quality goal, or it may decide to change its target quality value. As the cycle time values of individual activities are known, alternative business process models can be designed and computed to observe which arrangement of

[1] On the basis of definitions by Organisation B, one day consists of eight hours or 480 minutes, one week consists of five days, and one month consists of twenty days.

activities works best for achieving the target quality value (e.g., having activities executed in parallel whenever possible, or reducing/merging decision points, etc.).

8.4.2. Bottleneck Analysis

Computation reveals bottlenecks and the parts/activities that contribute most to the business process cycle time. Figure 60 demonstrates a bottleneck analysis of this business process depicting the composition of each part with different constituent activities or other parts. The contribution of each part/activity to the total cycle time is computed on the basis of the probability and the cycle time of the part/activity. This contribution is presented as a percentage of the total cycle time of the business process. On the basis of their severity, the critical parts are differentiated in different colours: red (high: above 20%), yellow (medium: between 8-19.99%), and grey (low: 5-7.99%). For each part of the process with severity, their components with the highest cycle time are also highlighted to show the component with the most impact. For example, Figure 60 shows that part V contributes the most to the cycle time of part X. Part V itself consists of parts, R, U, T, L, and D. Of these parts, part L and R have the highest severity and part U has a medium severity. In part L, “activity 45” time cycle has the most impact on the total cycle time of the business process. The complete analysis is presented in Table 29.

Figure 60 Bottleneck analysis of the business process

Table 29 Cycle time bottleneck analysis of the business process

Part	Severity	Cycle Time	Sub-part	Severity	Cycle Time	Activity	Severity	Cycle Time
L	High: 55.5%	47693	-----	------	-----	45	High: 23.5%	19215
						41	Medium: 17.16%	14017
						43	Medium: 8.82%	7201
						46	Medium: 8.26%	6720
R	Medium:14.5%	12440	I	Medium: 10.4%	8928	29	Low: 5.9%	4815
D	Medium: 14%	12078	------	-----	------	14	Low: 5%	4803
F	Medium: 9.7%	10565	-----	------	-----	18	Low: 8.82%	9605
U	Medium: 10%	8566.8	S	Medium: 9.2%	7928.9	37	Low: 6.1%	4800

Such an analysis can help managers to make informed decisions in business process management, for example in allocating resources, balancing the flow of activities, delegating tasks to experienced or knowledgeable staff, training staff, and automating business process activities or business process parts.

8.5. Evaluation of the Results

The measures developed in Section 6.4.2 for the evaluation process are revisited in this section, measuring (a) how effective is the BPIMM for this business process model, and (b) how effective is BP-QC in computing quality of the business process.

8.5.1. Evaluation of BPIMM

The goal is to provide a suitable answer to the question: *Can the business process integrating meta-model effectively specify the business process model in this case study?*

In this case study, BPMN is used to specify the business process. The extent to which the concepts and relationships in the business process model can be mapped onto the business process integrating meta-model's concepts and relationships is a concern for effectiveness. The evaluation measure developed in section 6.4.2 is used, showing the percentage of concepts and relationships of the business process model that can be mapped onto concepts and relationships in the integrating meta-model:

$$P_M = \frac{N_f}{N_C + N_r} \times 100$$

In the business process model, the following concepts are identified: lane, start event, end event, exclusive event, gateway, atomic activity, sequence flow and conditional sequence. These concepts and relationships map 1-1 to the concepts and relationships in BPIMM. Moreover, the relationships between these concepts are also covered by the relationships defined in the integrating meta-model. As a result, the coverage of the mapping onto the business process integrating meta-model is one hundred percent, demonstrating that the meta-model can provide a valid representation of the business process model.

8.5.2. Evaluation of BP-QC

Implemented in this case study, an evaluation of (a) BP-CQCF and algorithm, (b) business process patterns, and (c) computational formulae is conducted via answering the questions defined in the measurement model introduced in section 6.4.2.

a) *Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm*
   - Are the conceptual model and the method steps sufficient and effective for the purpose of computation?

BP-CQCF and algorithm are followed for the purpose of computation. The conceptual model and method steps are sufficient and effective in conducting the computation. As a result, there is no need for modification.

b) *Business process patterns*
   - Are the definitions of the business process patterns correct?

During the implementation, definitions of business process patterns are reviewed. The definitions are clear and consequently there is no need for modification.

   - Do they suffice?

With regards to the structure of the business process model, the business process patterns are sufficient for decomposing the business process. As a result, there is no need for modification.

   - Do all of the stakeholders' business process parts map 1-1 onto the proposed well-structured patterns?

The business process consists of some parts with embedded patterns, which makes a 1-1 mapping onto the proposed well-structured patterns infeasible. As a result, the process is restructured to make the mapping possible for the purpose of computation. The new parts are equivalent to the original parts. Where it is needed, new probabilities are calculated.

c) *Computational formulae*

- Are the computational formulae correct?

There is a need to change the proposed formulae for time estimation to consider different values "delay durations" associated with different probabilities before particular joints. As a result, a change is made in the definition of the computational formulae for time computation.

- Do they suffice?

Considering the change made, the set of formulae is sufficient for computing time in this case study. There is no need for adding new formulae for computing time.

8.6. Evaluation of the Approach by the Individual Stakeholders

In this section, the measures on utility evaluation (section 6.4.2) are revisited, capturing the views of stakeholders on the applicability, usability and usefulness of the approach. To this end, the researcher conducts semi-structured interviews with the business process stakeholders to evaluate the utility of the case study. Being recent graduates, the stakeholders together have more than five years of experience of working in Organisation B (a global financial institution) by the time of the interviews. The set of codes introduced in Section 6.4.2 is the basis for data analysis of the interviews. The three sub-codes of "Positive" (+), "Negative" (-) and "In Between" (+/-) are defined for each code, representing the interviewees' opinions. Table 30 provides an overview of the interviewees' opinions for different codes.

Table 30 Overview of the interviewees' opinions on different evaluation codes

		Interviewees		
		B1	B2	B3
Codes	Relevancy of quality factors and dimensions for the business process	+/-	N/A	+/-
	Overall relevancy of quality factors and dimensions	+/-	+	+
	Adequacy of quality factors and dimensions	+/-	+/-	+
	Overall usefulness of the approach	+	+	+
	Overall usability of the approach	+/-	+/-	N/A
	Support required for implementation	+	+	+

8

A factual report is provided from the interview data analysed by coding the data through the use of the ATLAS.ti 7.0 tool. Each statement in the report is accompanied by a closed parenthesis following this format: [#code of the interviewee: #Text Fragment Number in the transcript (T)] supporting the statement. Quotations from different stakeholders are separated by a "/" sign.

The outcome of this analysis with respect to the evaluation measures include:

- Relevancy and adequacy of the quality dimensions and factors.
- Overall usefulness of the approach.
- Usability and support required for the implementation.

Each following sub-section elaborates on each of these measures.

8.6.1. Relevancy and Adequacy of the Quality Dimensions and Factors

Relevancy: The objective is to evaluate the relevancy of the quality dimensions and factors introduced in Section 4.3 for the investigated business process as well as overall relevancy of the dimensions and factors. For the business process studied, the relevancy of performance [B1:T1/B3:T2,T3], efficiency [B1:T1/B3:T3], authority [B1:T2,T4] and reliability [B1:T1] dimensions is supported. The overall relevancy of quality dimensions and factors is reviewed during the interviews and is acknowledged by the interviewees [B1:T5/ B2:T1,T2,T4/B3:T5]. Specifically, relevancy of performance [B1:T5/B2:T1/B3:T5], efficiency [B1:T5/B2:T1], Reliability [B1:T5] and recoverability [B2:T1, T2 / B3:T5] is highlighted by the stakeholders. For the business processes using IT applications, availability of hardware and software is considered to be of importance [B1:T5]. However, due to rare occasions of down-times as well as maintenance times (e.g., during the night), this factor is not indicated to be as important as the aforementioned factors [B1:T5]. According to on stakeholder, "authority" is considered to be easily determined and visible in the way the work is distributed and the organisation is structured, so there is no need to follow the approach for computational purposes [B1:T5].

Adequacy: The objective is to evaluate the adequacy of the quality dimensions and factors introduced in Section 4.3, to examine whether a quality factor or dimension is missing from the list. The overall adequacy of the dimensions is confirmed by one of the stakeholders [B2:T6]. Considering the requirements of Organisation B, a need for defining a new quality factor called STP (Straight Through Processing) is highlighted [B1:T6]. STP basically indicates the percentage of entities that are going straight through the process without the need of having humans executing, adjusting, or correcting the process [B1:T6]. This factor is out of the scope of this thesis. The need for a new quality factor called FRT (First Time Right) is also highlighted [B2:T9]. This is categorised under the reliability dimension. The need for distinction between value added time and non-value added time is also highlighted, to which end the element of "cycle time" can be broken down to these elements [B2:T9].

Considering the philosophy behind the "performance" and "efficiency" dimensions (namely performing tasks as fast as possible, timely, and within the defined budget), the interviewees maintain that the risk associated with making mistakes due to such obligations should be considered and measured [B3:T8,T9,T11]. Also risk is out of the scope of this thesis.

8.6.2. Overall Usefulness of the Approach

The overall usefulness of the approach is reviewed during the interviews. The usefulness of the approach is confirmed. The value of the approach is highlighted as a data-driven and data-founded analysis [B1:T10]. Considering the measurement phase of Six Sigma, the approach is found useful, as both are data-driven for conducting evaluations [B1:T15]. It is maintained that, depending on the complexity and the goal of stakeholders, the approach is also applicable to other business processes and projects in the organisation [B1:T16/B2:T21/B3:T15,T17,T21]. Specially, the usefulness of the approach for complex processes and projects is indicated [B3:T16]. Further domains of application are suggested such as project management [B1:T20], IT development following the Agile/Scrum methodology [B1:T20], manufacturing [B2:T19], human resources [B2:T20], and, in general, wherever a customer is involved and performance is of importance [B2:T19]. Considering a low level of granularity and evaluating the quality of a business process in different parts is stated to provide a view of what is happening within the business process, rather than having the business process considered as a black box [B2:T7,T11,T14]. Moreover, it is affirmed that considering different aspects of quality provides a better view of the behaviour of a business process [B2:T11]. In addition, it is indicated that the set of quality factors and dimensions can be used as a basis for discussion about deciding suitable quality factors [B3:T14] as the list provides a complete view on different aspects [B2:T1/B3:T14]. It is also highlighted that comparing the results of the evaluation with the objectives defined by stakeholders is a plus, as they indicate areas for improvement; for this reason, the approach can be used in several domains [B2:T19/B3:T17].

8.6.3. Usability and Support Required for the Implementation

The usability and support required for implementation are covered in the interviews. Implementation of the approach is considered a concern. The need for using software for computation is indicated, as it makes the approach more usable, especially for complex and large business processes [B1:T10,T13]. It is stated that, as the approach is data-driven, collecting data is time consuming, and deployment of software should be considered [B1:T13]. Software should be user-friendly and usable for people who are not involved in the calculation [B1:T17/ B2:T7,T8,T21]. Software should be accompanied by a very easy user guide [B1:T17], practical examples [B1:T17], and a helpdesk providing technical support [B1:T18/B3:T17]. Interviewees indicate that the current way of using the approach (i.e., manually), and the trade-off between accuracy and the time required should be taken into account [B1:T11,T17]. The approach is considered to be high-value and a high-effort [B1:T19]. The "high-effort" aspect is a challenge for implementation, and therefore there is a need to make computation entail a lower-level of effort while maintaining high value [B1:T19].

The required support for the implementation of the approach is discussed. It is maintained that training should be considered to teach not only the "how" but also the "why" for grasping the usefulness of the approach [B2:T15]. This is maintained by clear explanations of the concepts and definitions as well as illustrative examples for the users [B3:T19].

8.6.4. Summary of the Evaluation by the Stakeholders

Revisiting the evaluation measures introduced earlier in this section, a summary of the evaluation by the stakeholders is provided:

- **Relevancy and Adequacy of the Quality Dimensions and Factors:**

Relevancy: For the business process studied, the relevancy of performance, efficiency, authority, and reliability dimensions is supported. The overall relevancy of the quality dimensions and factors is acknowledged and specifically the relevancy of performance, efficiency, reliability, and recoverability is highlighted. Availability is not considered to be as important as the other quality factors. As authority can be easily determined and is visible, the interviewee is of the opinion that there is no need for its computation.

Adequacy: While the adequacy of the quality dimensions and factors is confirmed by one stakeholder, the need for considering STP (Straight Through Processing) and the risks involved with the execution of a process and FRT (First Time Right) is highlighted by other stakeholders. STP factor and risk are is out of scope of the research whereas FRT can be categorised under the reliability dimension.

- **Overall Usefulness of the Approach:**

The value of the approach as a data-driven, data-founded analysis is appreciated in the measurement phase of the Six-Sigma. The approach is considered to be applicable to other business processes and projects in the organisation. The usefulness of the approach for the complex process and projects is indicated for domains such as project management, IT development following the Agile/Scrum methodology, manufacturing, human resources, and in general where performance is important and a customer is involved. The bottom-up view of the approach is appreciated. Consideration of different aspects of quality is deemed useful for providing a better view of a business process and as a basis for the discussion about deciding on suitable factors. Considering stakeholders' objectives in the approach also is expected to have a wide applicability in several domains.

- **Usability and Support Required for the Implementation:**

The implementation of the approach is a concern. The need for user-friendly computation software, accompanied by a very easy user guide, practical examples, and a help desk is indicated. The trade-off between accuracy and time should be taken into account as the approach is considered high-value and high-effort. Training about "how" and "why" as well as clear explanations of the concepts and definitions are considered of importance.

8.7. Chapter Summary

This chapter elaborates in a case study conducted for a real-life business process from Organisation B, which has not yet been implemented. The context, stakeholders, and their requirements are described. The business process integrating meta-model BPIMM is evaluated. On the basis of stakeholder requirements and availability of data, an estimation of cycle time at the business process level is conducted. A bottleneck analysis on the cycle time is made to provide insights about the business process. An effectiveness and utility evaluation of the findings is provided, based on the results acquired and on the feedback received from the stakeholders through interviews.

Chapter 9. Case Study Organisation C

Both the man of science
and the man of action
live always at the edge of mystery,
surrounded by it.
-J. Robert Oppenheimer

9.1. Introduction

This chapter elaborates on a case study conducted within Organisation C for a specific business process, namely accepting client. This business process is also used as a running example throughout the thesis for demonstration purposes.

The chapter is organised as follows. Section 9.2 introduces the context and stakeholders. Section 9.3 elaborates on the effectiveness of the integrating meta-model for this specific business process. Section 9.4 conducts the quality computation. Section 9.59.4.2 provides an evaluation on the results. Section 9.6 provides an evaluation on utility, and Section 9.7 provides a summary of the chapter.

9.2. Context, Stakeholders and Environment

Organisation C is an international financial service provider, that provides retail banking, wholesale banking, asset management, leasing and real estate services. The focus is on all-finance services in the Netherlands and on retail and wholesale banking, and food & agriculture internationally. The organisation provides services to ten million customers, with a ten thousands employees.

Six stakeholders with technology and management orientations are involved in the evaluation of the utility of the research. The roles of the stakeholders are shown in Table 31.

Table 31 Organisation C stakeholders involved in the evaluation as interviewees

ID	Role of the interviewee	Years of experience	Years of experience in the organisation	Interview Conduct
C1	Business process innovator	12	10	Telephone
C2	Manager of business process analysis	29	9	Group
C3	Business process analyst	37	25	Group
C4	Business process analyst	30	25	Group
C5	Business process analyst	30	30	Group

A summary of the approach is presented to the stakeholders. In a telephone interview and a focus group meeting, the opinions of the stakeholders on the utility of the approach are captured. Stakeholder validation of the research is in the scope of the case study. The following sub-sections elaborate on the case study conduction, and the evaluation.

Figure 61 depicts a simplified version of a real-world business process in BPMN, namely "Accepting client" provided by Organisation C. There are different departments/roles involved in this process. The process trigger is the arrival of a request to accept a client. To this end, a set of activities is performed in a predefined order.

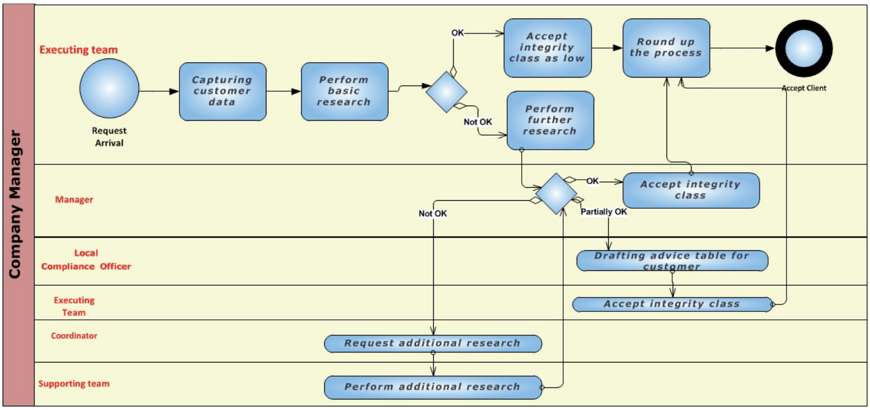

Figure 61 Accepting client business process

A demonstration of the applicability of the approach to the business process is presented to the stakeholders to capture their opinion on utility.

9.3. The Integrating Meta-Model Specification of the Business Process

In the business process, the following concepts are identified: lane, start event, end event, exclusive event, gateway, atomic activity, data object output, association, sequence flow, and conditional sequence. These concepts and their relationships are mapped 1-1 with the concepts and relationships identified in the integrating meta-model BPIMM.

9.4. Quality Computation of the Business Process

In this case study, for demonstration purposes data is generated and, computations at the business process concept level, and at the business process level are conducted. The following sections elaborate on each computation.

9.4.1. Measurement at the Business Process Concept Level

The quality requirement of "Capturing client data should be executed more than 95% of the time without failure" is defined by the company manager as a stakeholder of this process. This quality requirement is associated with the business processes concept of "Capturing client data" and is operationally queried by questions of "What is the percentage of the time that the execution is without failure out of the whole time of execution?" The quality factor "maturity" can be measured by a quality metric expressed as follows:

$$m(a)=\{upt(a)/[upt(a)+dot(a)\}*100$$

Where "a" denotes the "Activity", upt(a) is the "UPTime", and dot(a) is the "DownTime". The result of measurement is 78% showing a considerable difference with the target quality value (95%).

9.4.2. Estimation at the Business Process Level

The applicability of the approach is demonstrated for the running example, namely "Accepting Client" from Organisation C. Figure 62 illustrates the business process, using BPMN as a business process modelling language. As can be observed from Figure 62, there are different departments/roles involved in the process. The process trigger is the arrival of a request to accept a client. When the process is running, a set of activities is performed in a predefined order.

The business process's requirements include the following: "The outcome should be delivered within 16 weeks, as specified by the company manager." This requirement defines a limit for the cycle time of the business process.

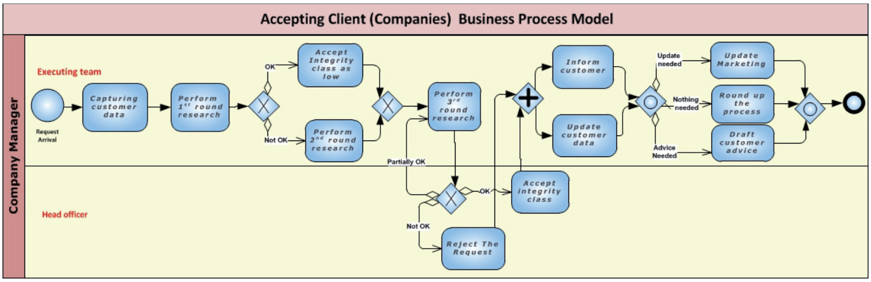

Figure 62 Accepting Client Business Process

Table 32 introduces the estimated/measured cycle time of each activity and their probabilities. A symbol for each activity is introduced for the ease of communication throughout the computation. One instantiation of the business process is generated for the purpose of demonstration. In the example provided, the client is accepted at the end process execution.

Table 32 Activities labels, probabilities, and computation results

Activity	Symbol		Result		Probability (estimation)
	M	E	M	E	
Capturing customer data	a	A	2	1	1.0
Perform 1st round research	b	B	3	2	1.0
Accept integrity class as low	c	C	4	3	0.7
Perform 2nd round research	d	D	1	2	0.3
Perform 3rd round research	e	E	2	2	0.3
Accept integrity class	f	F	3	5	0.6
Reject the request	g	G	4	3	0.1
Inform customer	h	H	1	1	1.0
Update customer data	i	I	2	2	1.0

Activity	Symbol		Result		Probability (estimation)
	M	E	M	E	
Update marketing	j	J	3	2	0.5
Round up the process	k	K	0	1	0.2
Draft customer advice	l	L	2	3	0.2

In line with the BP-QC approach introduced in Section 5.2, the quality of the business process is computed in different iterative phases, namely: decomposition, computation, and aggregation. In the first phase, the business process is decomposed into different parts according to the patterns introduced in Section 5.3[1] (Figure 63).

As can be observed from Figure 63, the patterns of sequential, exclusive, loop 1, parallel, and inclusive are present in the business process. The business process is decomposed into different parts on the basis of the identified patterns (i.e., decomposition).

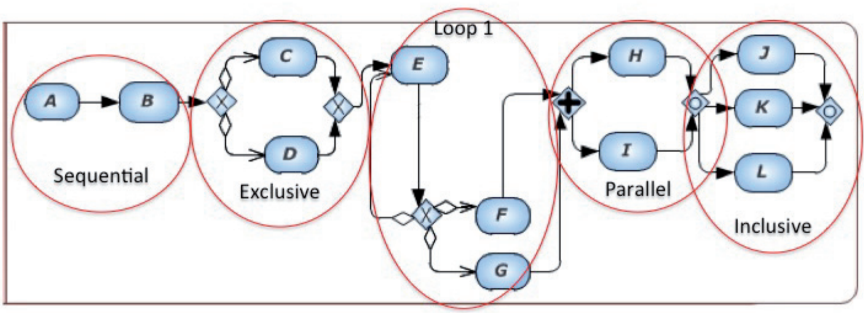

Figure 63 Patterns present in the business process

Each pattern is reduced to a single activity and computed (i.e., computation). In this example, the reduction is performed in different stages to provide a better understanding of the approach. Each time a reduction is applied, the business process structure changes (i.e., aggregation). In each stage, a few parts are reduced to a single activity and computed. The end result is one single activity as illustrated in Figure 65.

9

[1] For the matter of simplicity the uppercase letters are used for estimation and measurement in the diagrams

The computation is conducted both for measurement and estimation. Figure 64 depicts the instantiation for the measurement purpose; the activities executed in this instantiation are shown shaded. As observed, there is no loop iteration within this instantiation.

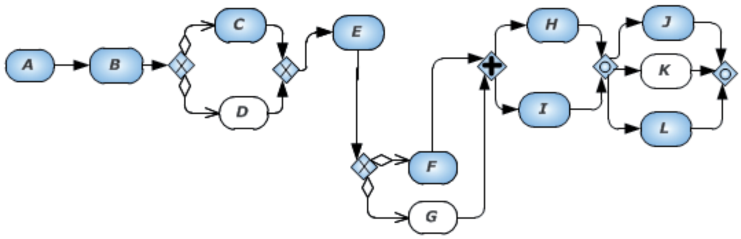

Figure 64 An execution of the business process

Either estimation or measurement of the activity flow is possible. Based on the reduction patterns, four steps toward complete reduction are involved in the calculation of cycle time (Figure 65). The result of reducing each set of activities is presented as another activity. The resulting activity label is indicated as the combination of the labels of the constituent activities; for example, in stage 1, reduction of the sequential pattern "A→B" is a single activity named "AB" and so on.

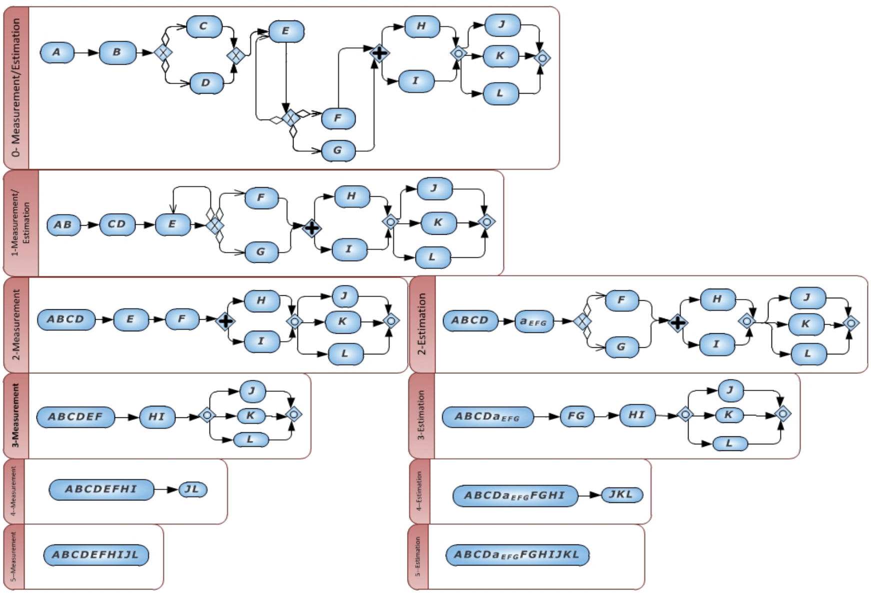

Figure 65 Stepwise reductions for estimation and measurement

Table 32 represents activity labels, the results of activity time measurement and activity time estimation (in weeks) and, if applicable, activity execution probability. For the inclusive patterns, four options exist: "J" with the probability of 50%, "K" with the probability of 20%, "L" with the probability of 20%, and "J and L" with the probability of 10%.

Given the formulae introduced in Section 5.4, Table 33 provides the formulae for calculation of the activities resulting from each reduction stage in the case of measurement and in the case of estimation. Where applicable, a new probability is introduced. As demonstrated, computation of requirement fulfilment of a business process is based on the results of its constituent concepts.

Table 33 The business process (reduced parts) computation

Measurement			Estimation			
Activity	**Formula**	**M**	**Activity**	**Formula**	**P**	**E**
ab	t(a) + t(b)	5	**AB**	T(A) + T(B)	1	3
cd	t(c)	4	**CD**	[T(C) × P(C)] + [T(D) × P(D)]	1	2.7
abcd	t(ab) + t(cd)	9	**ABCD**	T(AB) + TCD)	1	5.7
fg	t(f)	3	**a_{EFG}**	T(E) / (1 - p(E))	1	2.86
abcdefg	t(abcd) + t(e) + t(fg)	14	**FG**	$[P_{new}$ (F) × T(F)]+ $[P_{new}$ (G) × T(G)] P_{new} (F)= P(F)/[P(F)+P(G)] P_{new} (G)= P(G)/[P(F)+P(G)]	p_{new}(F)= 0.857 p_{new}(G)= 0.143	4.71
hi	Max{t(h),t(i)}	2	**ABCDa_{EFG}**	T(ABCD) + T(a_{EFG})	1	8.56
abcdefghi	t(abcdefg) + t(hi)	16	**HI**	Max{T(H), T(I)}	1	2
jl	Max{t(j), t(l)}	3	**JL**	-----	0.1	----
abcdefghijl	t(abcdefghi) + t(jl)	19	**ABCDa_{EFG}FGHI**	T(ABCDa_{EFG}) + T(FG) + T(HI)	1	15.27
---	---	--	**JKL**	P(J) × T (J) + P(K) × T(K) + P(L) × T(L) + P (JL) × Max{T(J) , T(L)}	1	2.1
---	---	--	**ABCDa_{EFG}EFHI JKL**	T(ABCDa_{EFG}EGHI) + T(JKL)	1	17.37

9

Based on these results, the manager can see the gaps between real values, estimated values, and quality targets. In the current design of the business process and with the current process participants, the process is computed to take 19 weeks, based on measurements, and 17.37 weeks, based on estimates, whereas the requirement is that it takes at most 16 weeks. Given this gap, the manager might decide to change either the business process or the requirement.

The benefit of this approach is that the computation is quantitative, and data-driven. This provides useful information for stakeholders: they know the actual performance of a business process, its estimated performance, and deviations from the given quality requirements. Moreover, knowing the quality of each single activity and of different parts of a business process enables managers to find out which concept or part of the process needs to be improved to improve the quality of the business process as a whole.

9.5. Evaluation of the Results

9.5.1. Evaluation of BPIMM

The goal is to provide a suitable answer to the question: *Can the business process integrating meta-model effectively specify the business process model in this case study?*

In this case study, the business process modelling language BPMN is used to specify the business process. See Figure 62 for details of the BPMN model of 'accepting client'. The extent to which the concepts and relationships in the business process model are mapped onto the business process integrating meta-model's BPIMM's) concepts and relationships is used as a measure for effectiveness in this thesis. The evaluation measure developed in section 6.4.2 is used, showing the percentage of concepts and relationships of the business process model that can be mapped onto concepts and relationships in the integrating meta-model:

$$P_M = \frac{N_f}{N_C + N_r} \times 100$$

In the business process, the following concepts are identified: lane, start event, end event, exclusive event, gateway, atomic activity, data object output, association, sequence flow, and conditional sequence. As these concepts and their relationships are mapped 1-1 with the concepts and relationships identified in the integrating meta-model BPIMM, BPIMM provides a valid representation of the business process model.

9.6. Evaluation of the Approach by Individual Stakeholders

In this section, the measures on utility evaluation (section 6.4.2) are revisited, capturing the views of the stakeholders on the applicability, usability, and usefulness of the approach. To this end, the researcher conducts semi-structured interviews with the stakeholders. Together, the stakeholders have more than 138 years of experience and more than 99 years of working in Organisation C by the time of the interviews. One telephone interview and one group interview are conducted.

A set of codes introduced in Chapter 6, Section 6.4.2, is the basis for data analysis of the interviews. The three sub-codes of "Positive" (+), "Negative" (-) and "In Between" (+/-) are defined for each code, representing the interviewees' opinions. Table 34 provides an overview of the interviewees' opinions for different codes.

Table 34 Overview of the interviewees' opinions on different evaluation codes

		Interviewees				
		C1	C2	C3	C4	C5
Codes	Relevancy of quality factors and dimensions for the business process	+/-	+/-	+/-	+/-	N/A
	Overall relevancy of quality factors and dimensions	+	+	N/A	N/A	N/A
	Adequacy of quality factors and dimensions	+/-	+	+	+	+
	Overall usefulness of the approach	+	+	+	N/A	+
	Overall usability of the approach	+/-	+/-	N/A	N/A	
	Support required for implementation	+	+	N/A	N/A	+

A factual report is provided from the interview data analysed by coding the data through the use of the ATLAS.ti 7.0 tool. Each statement in the report is accompanied by a closed parenthesis following this format: [#code of the interviewee: #Text Fragment Number in the transcript (T)] supporting the statement. Quotations from different stakeholders are separated by a "/" sign.

The outcome of the analysis with respect to the evaluation measures discusses:

- Relevancy and adequacy of the quality dimensions and factors.
- Overall usefulness of the approach.

- Usability and support required for the implementation.

The following sub-sections elaborate on each of these measures. At the end, a summary of the findings is provided.

9.6.1. Relevancy and Adequacy of the Quality Dimensions and Factors

Relevancy: The objective is to evaluate the relevancy of the quality dimensions and factors introduced in Section 4.3 for the investigated business process, as well as overall relevancy of the dimensions and factors. The overall relevancy of quality dimensions and factors are reviewed during the interviews and are acknowledged by the interviewees [C1:T6/C2:T46,T67]. Depending on the process, some factors are considered to be much more important [C1:T6,T8] than others, depending on the product and services provided and also the standard the organisation adheres to [C1:T6]. For the business process ‘accepting client’, reliability [C1:T15/C3:T45,T54], recoverability [C2:T15/C3:T1], performance [C1:T15/C2:T23,T34/C3:T17,T38/C4:T24], and authority [C2:T53/C4:T52] are highlighted as important.

Adequacy: The objective is to evaluate the adequacy of the quality dimensions and factors introduced in Section 4.3, to examine whether a quality factor or dimension is missing from the list. One interviewee indicated that the list would be more complete if the quality factor “compliance” were included [C1:T7].

9.6.2. Overall Usefulness of the Approach

The overall usefulness of the approach is reviewed during the interviews. The usefulness is confirmed, and a number of other applications for the approach are mentioned. Recognising that metrics have a unique implementation per domain [C1:T11], could be to define relevant metrics and quality factors for process mining [C1:T10, T13] and simulation [C1:T13]. More importantly, the approach is considered to be an “add on” to the business process management cycle [C1:T10]. It is affirmed that the approach can be used during the business process design phase to assure quality-oriented design and to determine what is relevant for measurement, and also at the end phase of business process management cycle to assess the quality of a business process [C1:T11,T12,T17/C2:109/C3:T91]. It is highlighted that the deliverables can be linked to different stages of the improvement cycle to make it more agile, practical, and useful [C1:T21]. Moreover, the applicability of the approach in the CER triangle (i.e., Commerce, Efficiency, and Risk) is recognised, given that the quality factors can be realised in different parts of the triangle [C5:T92/C2:T106/C5:T105].

Consideration of non-functional requirements upfront is expected to reduce the amount of energy and time currently spent afterwards on corrections of conflicts and test failures [C2:T65,T66]. The approach can be used in the design phase, helping business process designers and analysts to reflect on what measures are relevant and, and as an instrument and a basis for discussion between designers [C1:T12,T13/C2:T67/C3:T91]. Creating a set of internal questions or a checklist can help to keep all quality dimensions in mind [C2:T76]. Requirements of the business can be reflected in these quality factors and used in an analysis [C1:T17]. It is recommended to compare the internal definitions and perceptions of quality factors and metrics within the organisation to the definitions within this thesis, to detect possible differences and determine how to resolve them, for instance by changing the definitions within this thesis for a specific domain or context [C1:T17].

The importance of specification of different levels of granularity of a business process for quality computation is indicated [C1:T18,T19], and the levels distinguished are considered to be relevant [C1:T18]. While the highest abstract level of a business process is more understandable for most people, the lowest level of granularity (e.g., the activity level) becomes more important for implementation of the business process [C1:T18,T19]. Also, relatively more attention is given to the lowest level of granularity in applications such as process mining [C1:T18]. To foster transparency at all levels, the elements of a quality measure should be split up to the lowest meaningful level (e.g., cycle time encompassing execution time, synchronisation time, and queue time) [C1:T18]. Considering very small elements contributing to a quality aspect (e.g., time) fosters transparency in all levels; therefore, splitting up the elements of a quality measure becomes important. [C1:T18]. It is highlighted that possible variations in the perception of a quality aspect at different levels should be taken into account [C1:T18].

9.6.3. Usability and Support Required for Implementation

The usability and support required for implementation is reviewed during the interviews. Taking the implementation [C1:T12/C2:T100] and automation of computation into account will make the approach more usable [C1:T12,T15]. Availability of data influences the choice of metrics for a business process [C1:T10,T11]. Thus, in the design phase of the business process management cycle, the prerequisites and inputs for measuring quality in reality should be thought through upfront, to prevent changes afterward in the logs [C1:T10]. Additionally, it is maintained that a higher-level view of related fields such as "data quality" and "model quality" is required to understand the relations between these fields, with the aim of using the approach appropriately with well-defined quality processes [C2:T76,T77].

It is suggested that a set of decision rules or some level of automation can be used to assign relevant quality factors and metrics [C1:T15]. Whether or not this assignment can be performed automatically for all processes or manually should be a subject of discussion with the process owner [C1:T15]. Discussions should be facilitated as much as possible, to avoid incorrect interpretation [C1:T15].

The need for business process owners to learn the approach, to acquire an understanding of the quality factors, their importance and relevancy to their current processes, demands time [C1:T10,T14]. Relevant stakeholders will need to confirm the usefulness of the approach and their willingness to deploy the approach [C1:T14/C2:T100,T113]. This is marked as a challenging task [C2:T109,T100], as a sponsor is needed for the implementation of the approach [C1:T15]. Definitions of quality factors and metrics may need to be redefined for a specific context to be implemented or perhaps for specific audiences such as customers [C1:T15,T16]. Definitions should not be open for further interpretation [C1:T15,T16]. A set of definitions plus proven application for five to six examples can facilitate the discussion with a business process owner about (1) the necessity for consideration of the quality dimensions and (2) an implementation of the approach (e.g., factors to be added, or changes to be made) [C1:T16]. Whilst acquiring knowledge for quality computation is of importance, the use of knowledge in a persistent way is mentioned as a concern for all stakeholders involved in the process management cycle; this demands embedding knowledge into procedures [C2:T111,T113/C5:T110].

9.6.4. Summary of the Evaluation by the Stakeholders

Revisiting the evaluation measures introduced earlier in this section, a summary of the evaluation by the stakeholders is provided:

- Relevancy and adequacy of the quality dimensions and factors:

Relevancy: The overall relevancy of quality dimensions and factors are reviewed during the interviews and are acknowledged by the interviewees. Depending on the process, some factors are more important than others. For this business process, reliability, recoverability, performance, and authority are considered to be of most importance.

Adequacy: One interviewee indicated that the list would be more complete if the quality factor “compliance” is included.

- Overall usefulness of the approach:

Usefulness is confirmed, and several different applications for the approach are mentioned including process mining, business process management cycle, and management of the CER triangle (i.e., Commerce, Efficiency, and Risk). Implementation of metrics will differ per domain of application. The approach can be used in the design phase, helping business process designers and analysts to reflect on relevant aspects that need to be measured. Internal definitions and perceptions of quality factors and metrics within the organisation should be compared to the definitions within this thesis, to detect possible differences and to determine how they should be resolved. The different relevant levels of granularity of a business process for quality computation are of importance. Considering lower level aspects that contribute to a quality aspect (e.g., time) fosters transparency in all levels;

therefore, splitting up the elements of a quality measure is important. Variations in the perception of a quality aspect at different levels should be taken into account.

- Usability and support required for the implementation:

There is a need to take implementation and automation of computation into account. Availability of data influences the choice of metrics for a business process. Additionally, it is maintained that a higher-level view of related "quality" fields is required to use the approach proposed in this thesis appropriately. The usefulness of the approach is confirmed by the stakeholders. The need for context and audience-dependent definitions that are not open for interpretation is identified. Whilst acquiring knowledge for quality computation is considered of importance, the use of knowledge in a persistent way is mentioned as a concern.

9.7. Chapter Summary

This chapter elaborates on the case study "accept client" conducted within Organisation C, an international financial service provider. An evaluation of the effectiveness BPIMM and the utility of BPC-QC and BP-QC is provided on the basis of the feedback received from stakeholders via a telephone interview and a focus group meeting. The viewpoints of the stakeholders on aspects of “relevancy and adequacy of quality dimensions and factors,” “overall usefulness of the approach,” and “usability and support required for implementation” provide insights on possible extensions of the approach.

Chapter 10. Case Study Organisation D

….No amount of experimentation can ever prove me right;
a single experiment can prove me wrong.
-Albert Einstein

10.1. Introduction

This chapter elaborates on a case study conducted within the SlimVerbinden project (Organisation D) for a specific crisis management scenario, with a large number of multiple stakeholders. This chapter explores the usefulness and usability of the approach that this thesis proposes for this context. The scope encompasses authority computation at both the business process concept level as well as the business process level. The business process integrating meta-model (BPIMM) and the effectiveness of computing the quality of business processes and its concepts (BPC-QC and BP-QC) are evaluated.

This chapter is organised as follows. Section 10.2 describes the context and stakeholders and the environment. Section 10.3 provides a mapping of the business process onto the business process integrating meta-model. Section 10.4 elaborates on the business process quality computation. Section 10.5 describes an effectiveness evaluation of the findings. Section 10.7 reports on a utility evaluation, and Section 10.7 provides a summary of the chapter.

10.2. Context, Stakeholders and Environment

The project 'SlimVerbinden' addresses the challenge of incident management (de Bruijn and Wijngaards, 2013). All parties involved retain autonomy while sharing information and ensuring prevention of misuse of information (Genc et al., 2013). Together with stakeholders from industry, the municipality, the safety region, the police, etc., SlimVerbinden analyses a scenario based on an actual threat analysis of a steel factory (Tata Steel) in a densely populated area in the Netherlands. The steel factory spans a large area with many installations, pipelines, valves, storage units, etc. A number of the chemicals and products in this factory are a hazard to the environment, health, and safety of the population.

Three stakeholders whom have been actively involved in the project from different organisations with both technology and management orientations are involved in the evaluation of the utility of the research. The stakeholders are actively involved in follow-up projects, namely "Bridge" (Stakeholder D1) and "Alerting as a Service" (Stakeholders D2 and D3). The roles of the stakeholders are shown in Table 35.

Table 35 Organisation D stakeholders involved in the evaluation as interviewees

ID	Role of the interviewee	Years of experience	Years of experience in the organisation	Interview conduct
D1	Senior researcher, Program manager	20.5	7	One-to-One
D2	Director/Change manager	25	8	One-to-One
D3	CIO, Lector	25	6	Telephone

A summary of the approach is presented to the stakeholders as well as the application for Organisation D. In one-to-one/telephone interviews, the opinion of the stakeholders on the utility of the approach is captured.

The quality estimation and measurement of the business process and its concepts are in the scope of the evaluation. Note that the data is generated for the purpose of demonstration of the applicability of the approach.

The context is defined by a scenario that starts with a report from a civilian about a gas leak, requiring multiple data flows between involved parties. These parties have different needs and responsibilities and, in most cases, only cooperate with each other in a crisis situation. In such a situation, they need to be able to depend on each other. Individual stakeholders can grant other parties access to information. They can delegate access to specific stakeholders within their own organisation. Other external stakeholders provide additional information on, for instance, the availability of resources, incident-specific information, weather forecasts and danger estimations.

As many new incidents differ from previous incidents, stakeholders are frequently faced with novel situations: it is impossible to predict in advance what information is required and possibly relevant. Decisions often have to be immediate. It is assumed that, due to time pressure, not all activities are performed by authorised stakeholders.

The quality requirements in this case are identified based on previous experience and norms, or, as (Saeedi et al., 2010) states, “the data relating to the actual work performed by a process”. The quality requirement for authority is expressed as follows:

The violation of authority more than 10% during the execution is not acceptable.

Figure 66 illustrates the business process in the business process modelling language BPMN with respect to “authority”. A level of authority is identified and its satisfaction can be measured or estimated for analysis purposes. Activities for which the authority can be violated have thicker borders. The activities are coloured for which authority is known to be violated (or, in the case of estimation, are predicted to be violated). The BPMN model of the scenario is used in the communication with the parties involved in this project (the stakeholders), to design the SlimVerbinden demonstrator and to evaluate the distributed information infrastructure. The demonstrator is used to illustrate what would and could happen during a disaster, as a trigger for stakeholders to assess their own individual situations and their interaction with others.

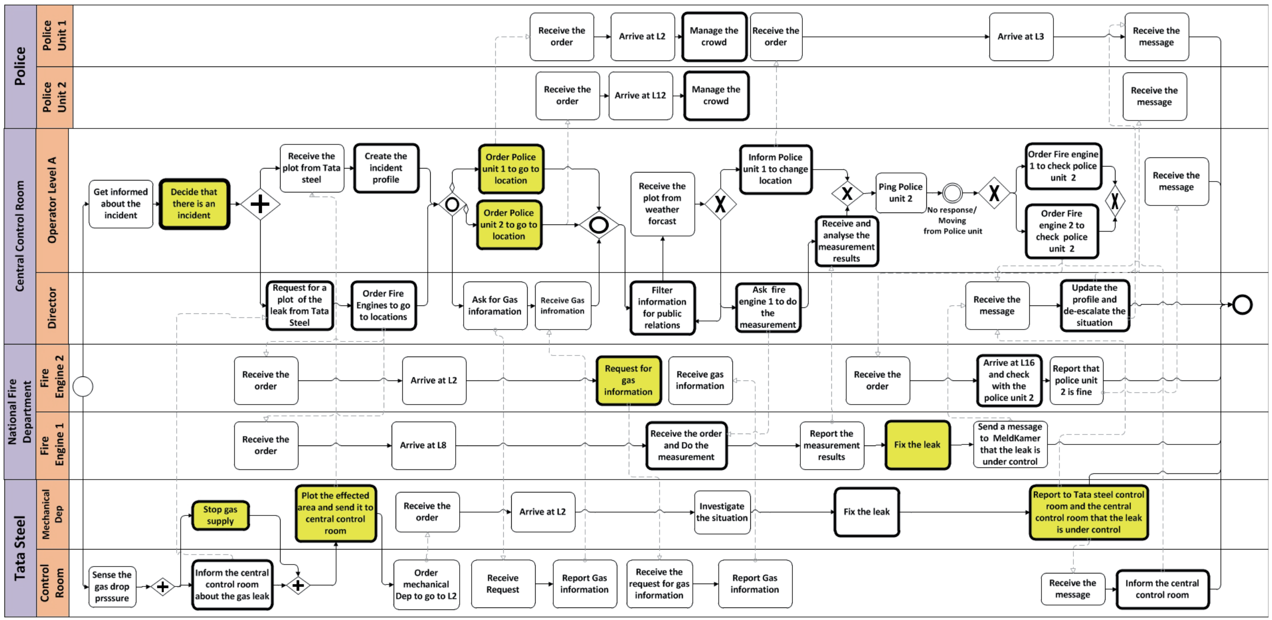

Figure 66 SlimVerbinden scenario in BPMN

10.3. The integrating Meta-model Specification of the Business Process

In the business process, the following concepts are identified: lane, start event, end event, intermediate event, exclusive event, gateway, atomic activity, data object output, association, sequence flow and conditional sequence. These concepts and their relationships are covered by the concepts and relationships introduced in the integrating meta-model.

10.4. Quality Computation of the Business Process

In this case study, a computation at the business process concept level and a computation at the business process level are conducted. The following sections elaborate on each computation.

10.4.1. Computation at the Business Process Concept Level

The following set of formulae recaps the metrics for an activity authority measurement introduced in Section 4.3.5.

M	$u(a) = \{1 - \sum_{k=1}^{n}[w_k \times uv_k\,(a)]\} \times 100$ $uv_K\,(a) = 1$ if activity "a" is performed by unauthorised actor "k" $uv_K\,(a) = 0$ if activity "a" is performed by authorised actor "k" $\sum_{k=1}^{n} uv_k(a) \leq 1$ $w_k \leq 1$	$u(a)$ = aUthority measurement of an activity $uv_k(a)$ = activity aUthority Violence by actor "k" w_k= Weight of actor "k" n= number of actors

Table 36 represents authority measurement results for different activities. For ease of communication, the name of each activity is replaced by a uppercase letter as its symbol. The data is generated for the purpose of demonstration of the applicability of the approach.

Table 36 Activities' authority measurement

Symbol	Activity (a)	Authorised actor $[uv_K(a) = 0]$	Violating actor $[uv_K(a) = 1]$	Weight of the violating actor(w_k)	Measurement Result $u(a)$
a	Decide that there is an incident	*Director*	*Operator Level A*	*0,1*	*90*
b	Create the incident profile	*Operator level A /Director*	---	*0*	*100*
c	Request for a plot of the leak from Tata Steel	*Director*	---	*0*	100
d	Order Fire Engines to go to locations	*Director*	---	*0*	100
e	Order Police unit 1 to go to locations	*Director*	*Operator Level B*	0,5	*50*
f	Order Police unit 2 to go to location	*Director*	*Operator Level B*	0,3	*70*
g	Manage the crowd	*Police Unit 1&2*	---	*0*	100
h	Manage the crowd	*Police Unit 1&2*	---	*0*	100
i	Filter information for public relations	*Director*	---	*0*	100
j	Inform Police unit 1 to change location	*Operator Level A /Director*	---	*0*	100
k	Ask fire engine 1 to do the measurement	*Operator/Director*	---	*0*	100
l	Receive and analyse the measurement results	*Operator Level A/Director*	---	*0*	100
m	Order fire engine 2 to check police unit 2	*Operator Level A /Director*	---	*0*	100
n	Order fire engine 1 to check police unit 2	*Operator Level A /Director*	---	*0*	100
o	Update the profile and de-escalate the situation	*Director*	---	*0*	100

Symbol	Activity (a)	Authorised actor $[uv_K(a) = 0]$	Violating actor $[uv_K(a) = 1]$	Weight of the violating actor (w_k)	Measurement Result $u(a)$
p	Stop gas supply	*Tata Steel Control Room*	*Mechanical Department*	*0,1*	*90*
q	Inform the central control room about the gas leak	*Tata Steel Control Room*	---	*0*	100
r	Plot the effected area and send it to central control room	*Tata Steel Control Room*	*Mechanical Department*	*0,1*	*90*
s	Fix the leak	*Mechanical Department/ Fire Engine 2*	---	*0*	100
t	Request for gas information	*Fire Commander*	*Fire Engines*	*0,1*	*0*
u	Receive the order and do the measurement	*Fire Engine 1 and/or 2*	---	*0*	100
v	Fix the leak	*Fire Engine 2/ Mechanical Department*	*Fire Engine 1*	*0,6*	*40*
z	Arrive at L16 and check with the police unit 2	*Fire Engine 1 and/or 2*	---	*0*	100
w	Report to the central control room that the leak is under control	*Tata Steel control room*	---	*0*	*100*
y	Inform the central control room	*Tata Steel control room*	---	*0*	100

The following set of formulae recaps the metrics for an activity authority estimation introduced in Section 4.3.5.

E	$U(A) = \{1 - \sum_{k=1}^{n}[W_k \times P_k(A) \times UV_k(A)]\} \times 100$ $UV_K(A) = 1$ if activity "A" is performed by unauthorised actor "K" $UV_K(A) = 0$ if activity "A" is performed by authorised actor "K" $\sum_{K=1}^{n} P_K(A) = 1$ $W_K \leq 1$	U(A)= aUthority of an Activity $UV_k(A)$ = Activity aUthority Violence by actor "k" W_K = Weight of actor "K" n = number of actors $P_k(A)$ =Probability of execution by actor "K"

Table 37 represents authority estimation results for different activities.

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Table 37 Activities authority estimation results

Symbol	Activity (a)	Authorised actor [UV_K (A) = 0]	Potential violating actor [UV_K (A) = 1]	Probability of execution by the violating actor $P_k(A)$	Weight of the violating actor (W_k)	Estimation Result U(A)
A	Decide that there is an incident	*Director*	*Operator Level A*	*0,2*	*0,1*	*95*
			Operator Level B	*0,1*	*0,3*	
B	Create the incident profile	*Operator level A /Director*	*Operator level B*	*0,5*	*0,5*	*75*
C	Request for a plot of the leak from Tata Steel	*Director*	*Operator Level A*	*0,3*	*0,1*	*93*
			Operator Level B	*0,1*	*0,4*	
D	Order Fire Engines to go to locations	*Director*	*Operator Level A*	*0,3*	*0,1*	*93*
			Operator Level B	*0,1*	*0,4*	
E	Order Police unit 1 to go to locations	*Director*	*Operator Level A*	*0,3*	0,1	*92*
			Operator Level B	*0,1*	0,5	
F	Order Police unit 2 to go to location	*Director*	*Operator Level A*	*0,3*	0,1	*94*
			Operator Level B	*0,1*	0,3	
G	Manage the crowd	*Police Unit 1&2*	*Other police units*	*0,3*	*0,3*	*91*
H	Manage the crowd	*Police Unit 1&2*	*Other police units*	*0,3*	*1*	*70*
I	Filter information for public relations	*Director*	*Operator Level A*	*0,3*	*0,2*	*89*
			Operator Level B	*0,1*	*0,5*	

Symbol	**Activity** (a)	Authorised actor [UV_K (**A**) = **0**]	Potential violating actor [UV_K (**A**) = **1**]	Probability of execution by the violating actor $P_k(A)$	Weight of the violating actor (W_k)	Estimation Result **U**(a)
J	Inform Police unit 1 to change location	*Operator Level A /Director*	*Operator Level B*	*0,3*	*0,6*	*82*
K	Ask fire engine 1 to do the measurement	*Operator/Director*	*Operator Level B*	*0,4*	*0,2*	*92*
L	Receive and analyse the measurement results	*Operator Level A/Director*	*Operator Level B*	*0,2*	*0,7*	*86*
M	Order fire engine 2 to check police unit 2	*Operator Level A /Director*	*Operator Level B*	*0,4*	*0,1*	*96*
N	Order fire engine 1 to check police unit 2	*Operator Level A /Director*	*Operator Level B*	*0,5*	*0,2*	*90*
O	Update the profile and de-escalate the situation	*Director*	*Operator Level A*	*0,2*	*0,5*	*70*
			Operator Level B	*0,1*	*1*	
P	Stop gas supply	*Tata Steel Control Room*	*Mechanical Department*	*0,3*	*0,1*	*97*
Q	Inform the central control room about the gas leak	*Tata Steel Control Room*	*Mechanical Department*	*0,2*	*0,3*	*94*
R	Plot the effected area and send it to central control room	*Tata Steel Control Room*	*Mechanical Department*	*0,3*	*0,1*	*97*
S	Fix the leak	*Mechanical Department/ Fire Engine 2*	*Local fire department*	*0,3*	*1*	*70*
T	Request for gas information	*Fire Commander*	*Fire Engines*	*0,6*	*0,1*	*94*
U	Receive the order and do the measurement	*Fire Engine 1 and/or 2*	*Other Fire Engines*	*0,2*	*0,2*	*96*

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Symbol	**Activity** (a)	Authorised actor [UV_K **(A) = 0**]	Potential violating actor [UV_K **(A) = 1**]	Probability of execution by the violating actor $P_k(A)$	Weight of the violating actor (W_k)	Estimation Result $U_e(A)$
V	Fix the leak	*Fire Engine 2/ Mechanical Department*	*Fire Engine 1*	*0,2*	*0,6*	*82*
			Other Fire Engines	*0,1*	*0,6*	
Z	Arrive at L16 and check with the police unit 2	*Fire Engine 1 and/or 2*	*Other Fire Engines*	*0,1*	*0,1*	*99*
W	Report to the central control room that the leak is under control	*Tata Steel control room*	*Mechanical Department*	*0,2*	*0,6*	*83*
			Local fire department	*0,1*	*0,5*	
Y	Inform the central control room	*Tata Steel control room*	*Mechanical Department*	*0,2*	*0,3*	*86*
			Local fire department	*0,1*	*0,2*	

10.4.2. Computation at the Business Process Level

For the sake of simplicity, a more succinct abstraction of the scenario is provided in Figure 67. This presentation just encompasses the activities prone to be violated (i.e., the ones shown in Figure 67 with thicker borders).

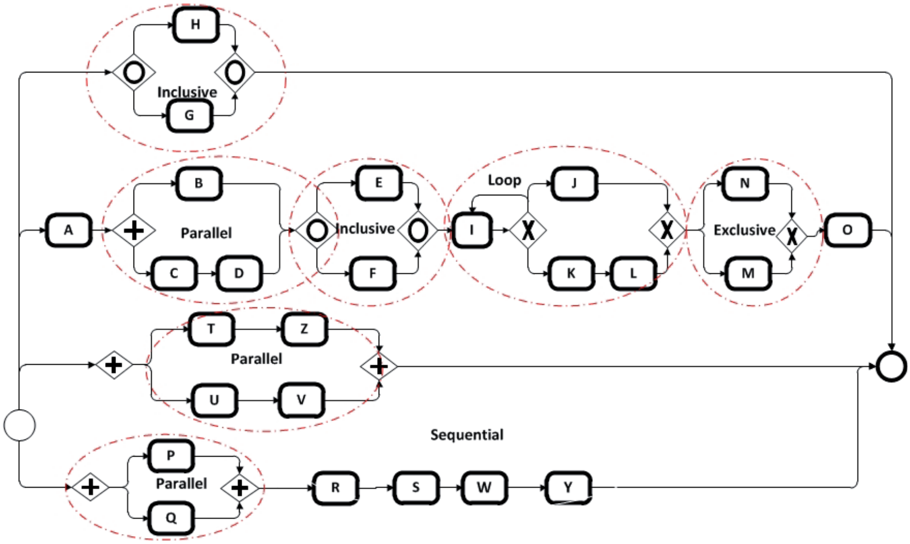

Figure 67 Examples of pattern recognition in the scenario model

As stated, exclusive and inclusive patterns are associated with probabilities. Choices in inclusive patterns can encompass more than one activity. Figure 68 illustrates the probabilities associated with the corresponding branches as well as the groups of activities that can be executed in the inclusive patterns.

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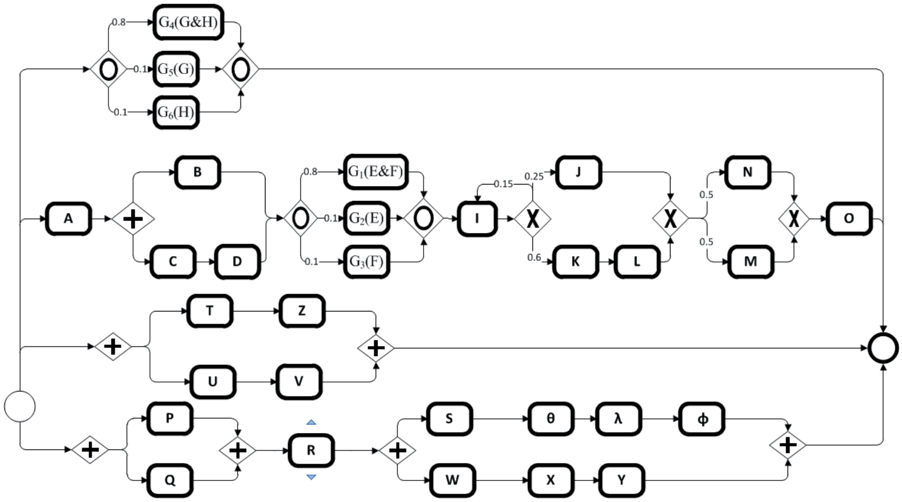

Figure 68 Probability specification in exclusive and inclusive patterns in the scenario model

This section describes how the authority of the activity is computed by reducing a pattern. The authority value of each activity is incorporated in the authority value of the whole business process. However, not all activities have the same influence on the authority value of a business process. Thus, different weights are allocated to different activities indicating the severity of violating authority (Table 38). For example, deciding whether there is really a gas leak in the area (activity A) is the most important activity involved, as shown in Table 38. If executed by an unauthorised person, it may put the lives of several people in danger.

Table 38 Authority weight distribution in the scenario

Symbol	Weight in Business Process (W)	Symbol	Weight in Business Process (W)
A	*0.2*	P	*0.06*
B	*0.01*	Q	*0.01*
C	*0.02*	R	*0.06*
D	*0.08*	S	*0.08*
$G_{1\text{-}3}$	*0.06*	T	*0.02*
$G_{4\text{-}6}$	*0.01*	U	*0.02*

Symbol	Weight in Business Process (W)	Symbol	Weight in Business Process (W)
J-KL	0.02	**V**	*0.06*
I-a_{IJKL}	*0.04*	**W**	*0.06*
M-N	*0.01*	**Y**	*0.06*
O	*0.1*	**Z**	*0.02*
Sum	***0.61***	***Sum***	***0.39***
Total Sum	**1**		

Each activity in "sequence" and "parallel" patterns has its own authority value. All activities in an exclusive pattern and all activities after a gateway in a "loop" pattern are assigned the same value; in other words, the effect of violating the authority for each choice is the same. In a "loop" pattern, for ease of calculation, authority values of the repeating activities are only considered once. For every inclusive pattern, all groups of activities have the same value of authority and within each group different weights can be assigned to its constituent activities (Table 39).

The value of each constituent activity of the pattern is assumed to be independent of those of the others. For example, in a sequence pattern where activities are executed one after another, no matter who violated an activity, the authority of its following activities will not be influenced. The result of reducing each set of activities is presented as another activity. The resulting activity symbol is indicated as the combination of the symbols of the constituent activities. For instance, in stage 1, reduction of the sequential pattern "C→D" is a single activity named "CD". The authority of an activity is denoted by U(a).

In line with the BP-QC approach introduced in Chapter 5, the authority of the scenario is computed in different iterative phases, namely: decomposition, computation and aggregation. In first phase the business process is decomposed into different parts according to the patterns introduced in Section 5.3. (i.e., *decomposition*). Then, each pattern is reduced into a single activity and computed (i.e., *computation*). Each time reduction is applied, the business process structure changes (i.e., aggregation). The end result is one single activity. With regards to the estimated and measured values of authorities of a single activity (Table 34, and Table 35), weights of activities (Table 36), and the formulae introduced in Chapters 4 and 5, measurement and estimations of authority within the scenario are conducted.

Table 39 Weights within each group and probability

Activity/choice	Probability	Activity	Weight within the group	Sum
G_1	0.8	E	0.45	1
		F	0.55	
G_2	0.1	E	--	--
G_3	0.1	F	--	--
G_4	0.8	G	0.3	1
		H	0.7	
G_5	0.1	H	--	--
G_6	0.1	G	--	--
I	0.15	I	--	--
J	0.25	J	--	--
K & L	0.6	K	0.4	1
		L	0.6	
N	0.5	N	--	--
M	0.5	M	--	--

The authority of the scenario is computed following the BP-QC approach and the above explanation. Figure 69 and Figure 70 demonstrate the steps taken for computing the authority. In each step, the patterns are reduced into a single activity and the business process is replaced by a more succinct structure until just one activity remains. Table 38 and Table 41 accompany Figure 69 and Figure 70 accordingly. With regards to the reduction steps, the resulting activities are computed and formulae for computation are introduced. The final rows of computation correspond to the final activity and computation of the whole business process.

Figure 69 illustrates the reductions taking place for the authority measurement within the scenario. The reduction takes four steps. The result of the reduction in the fourth step is a single activity, and the value associated to that activity is identical to the authority measurement value of the whole business process.

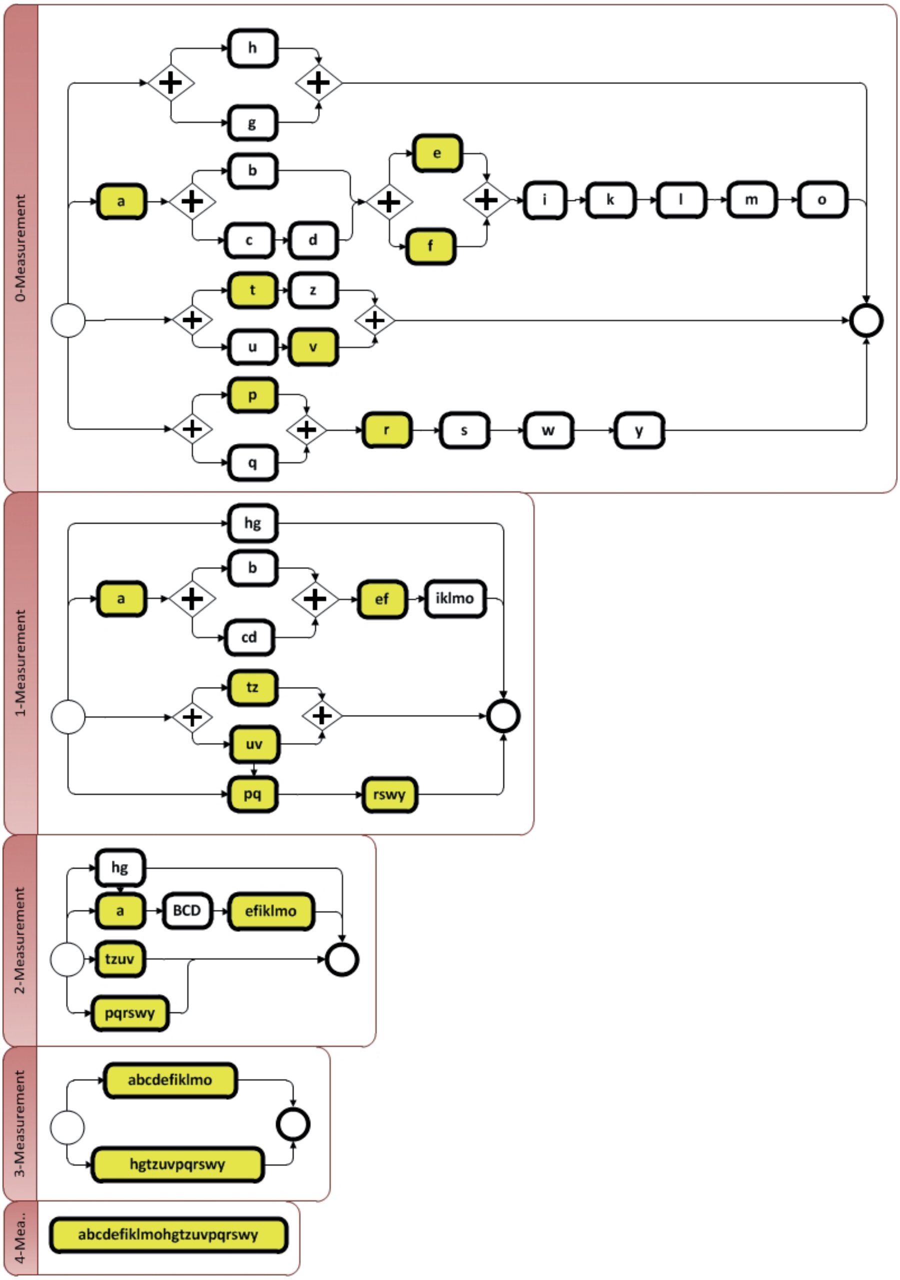

Figure 69 Stepwise reductions for measurement

Table 40 presents the formulae measuring the resulting activities of each reduction step (Figure 69).

Table 40 Authority measurement step-wise results

Step	Activity	Formula	Result
1	**hg**	$u(g_4)= w_{g_4}\times[w_{g_{4G}}\times u(g)+ w_{g_{4H}}\times u(h)]$	1
	cd	$w_c\times u(c)+ w_d\times u(d)$	10
	ef	$u(g_1)= w_{g1}\times[w_{g_{1E}}\times u(e)+ w_{g_{1F}}\times u(f)]$	3,66
	iklmo	$w_i\times u(i)$ + $w_{k\&l-k}\times u(k)+ w_{k\&l-l}\times u(l)+ w_{m\&n-m}\times u(m)+ w_o\times u(o)$	18,2
	tz	$w_t\times u(t)+ w_z\times u(z)$	2
	uv	$w_u\times u(u)+ w_v\times u(v)$	8
	pq	$w_p\times u(p)+ w_q\times u(q)$	1
	rswy	$w_s\times u(s)+ w_r\times u(r)+ w_w\times u(w)+ w_y\times u(y)$	14
2	**bcd**	$w_B\times u(b)+u(cd)$	10
	efikmno	u(ef)+u(iklmo)	21,86
	tzuv	u(tz)+ u(uv)	10
	pqrswy	u(pq)+ u(rswy)	15
3	**abcdefiklmo**	$w_A\times u(a)$+ u(bcd)+ u(efikmno)	49,86
	hgtzuvpqrswy	u(hg)+ u(tzuv)+ u(pqrswy)	26
4	**abcdefiklmohgtzuvpqrswy**	u(abcdefiklmo)+ u(hgtzuvpqrswy)	75,86

Figure 70 illustrates the five reduction steps for authority estimation of the scenario. The result of reduction in the fifth step is a single activity, and its associated value is identical to the authority estimation value of the whole business process.

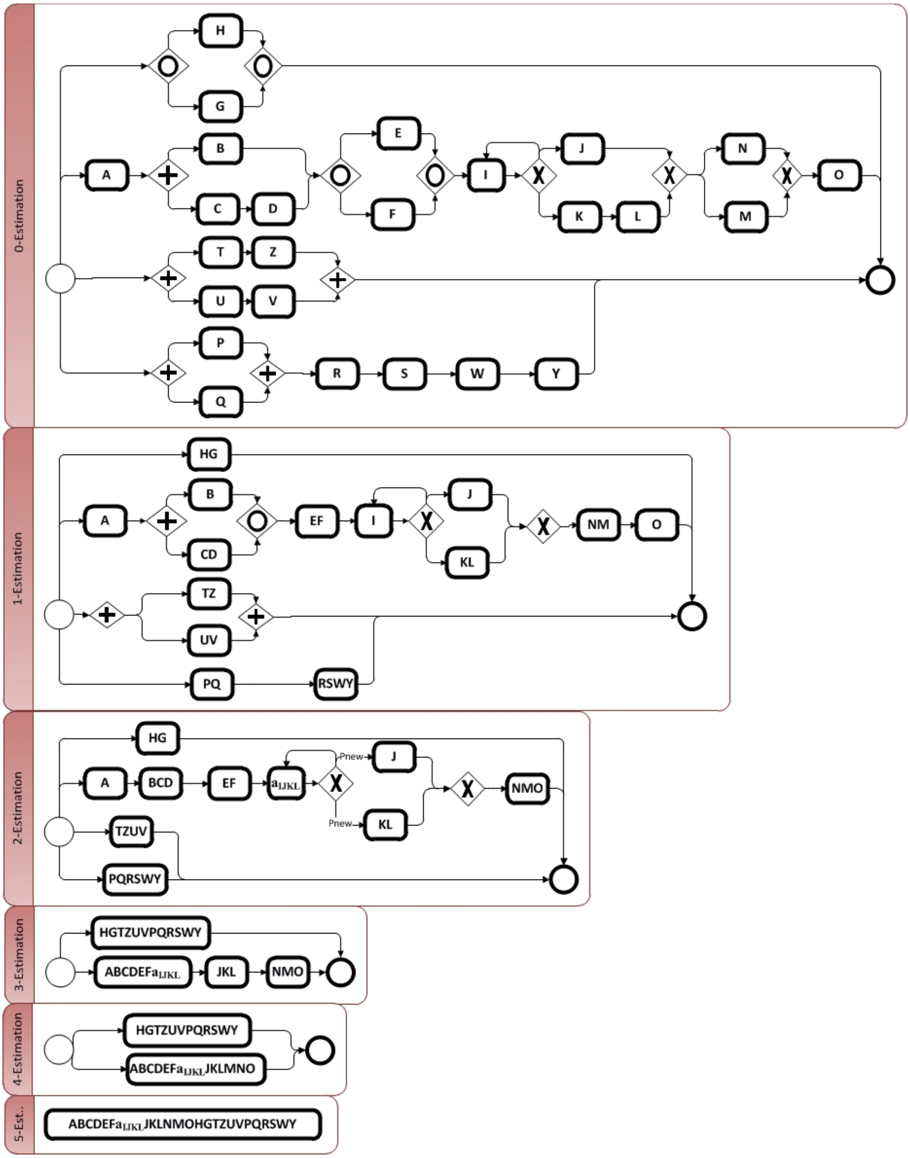

Figure 70 Stepwise reductions for estimation

Table 41 presents the formulae estimating the resulting activities of each reduction step (Figure 70).

Table 41 Business process authority estimation step-wise results

Step	*Activity*	*Formula*	*Result*
1	**HG**	$\sum_4^6 P(G_k) \times U(G_k) = P(G_4) \times [w_{G_4} \times (w_{G_{4G}} \times U(G) + W_{G_{4H}} \times U(H))] + P(G_4) \times [W_{G5} \times U(G)] + P(G_6) \times [W_{G6} \times U(H)]$	1,39
	CD	$W_C \times U(C) + W_D \times U(D)$	9,3
	EF	$\sum_1^3 P(G_k) \times W_{GK} \times U(G_K) = P(G_1) \times [W_{G_1} \times (W_{G_{1E}} \times U(E) + W_{g_{1F}} \times U(F))] + P(G_2) \times [W_{G2} \times U(E)] + P(G_1) \times [W_{G1} \times U(F)]$	9,53
	KL	$W_{K\&L} \times [W_{K\&L-K} \times U(K) + W_{K\&L-L} \times U(L)]$	1,77
	MN	$P(N) \times W_N \times U(N) + P(M) \times W_M \times U(M)$	0,93
	TZ	$W_T \times U(T) + W_Z \times U(Z)$	3,86
	UV	$W_U \times U(U) + W_V \times U(V)$	6,84
	PQ	$W_P \times U(P) + W_Q \times U(Q)$	6,76
	RSWY	$W_S \times U(S) + W_R \times U(R) + W_W \times U(W) + W_Y \times U(Y)$	17,88
2	**BCD**	$W_B \times U(B) + U(CD)$	10,05
	a_{IJKL}	$U(a_{IJKL}) = W_I \times U(I) / (1-P(I))$ $P_{new}(J) = P(J)/(1-P(I))$ $P_{new}(KL) = P(KL)/(1-P(KL))$	4,19
	MNO	$U(MN) + W_O \times U(O)$	7,93
	TZUV	$U(TZ) + U(UV)$	10,70
	PQRSWY	$U(PQ) + U(RSWY)$	24,64
3	**ABCDEFa_{IJKL}**	$W_A \times U(A) + U(BCD) + U(EF) + U(\mathbf{a}_{IJKL})$	42,02
	JKL	$P_{new}(J) \times W_J \times U(J) + P_{new}(KL) \times U(KL)$	1,73

Step	Activity	Formula	Result
	HGTZUVPQRSWY	U(HG)+ U(TZUV)+ U(PQRSWY)	36,73
4	**ABCDEFa$_{IJKL}$JKLMNO**	U(ABCDEFa$_{IJKL}$)+ U(JKL)+U(MNO)	51,68
5	**ABCDEFa$_{IJKL}$JKLMNOHGTZUVPQR SWY**	U(ABCDEFaIJKLJKLMNO)+U(HGTZUVPQR SWY)	88,42

Based on these results, gaps can be observed between the current situation, the estimated value, and the quality target. The quality requirement on authority is:

> *The violation of authority more than 10% during the execution is not acceptable.*

The result of measurement demonstrates a violation of authority by 24.14%. In addition, 11.58% of the authority of the process is estimated to be violated. The requirement that violation of authority may not exceed than 10% is not fulfilled.

10.5. Evaluation of the Results

The measures developed for the evaluation (Section 6.4.2) are revisited in this section, measuring (a) how effective the business process integrating meta-model (BPIMM) is in specifying the business process model, (b) how effective the metrics are to computing quality of the business process concepts (BPC-QC), and (c) how effective the approach is to computing quality of the business process (BP-QC).

10.5.1. Evaluation of the BPIMM

The goal is to provide a suitable answer to the question: *Can the business process integrating meta-model (BPIMM) effectively specify the business process model in this case study?*

In this context, BPMN is deployed for representing the business process. Mapping the concepts and relationships in the model onto the business process integrating meta-model's concepts and relationships is a concern. The evaluation measure developed in Section 6.4.2 is used, showing the percentage of concepts and relationships of the model that can be mapped onto the concepts and relationships in the integrating meta-model:

$$P_M = \frac{N_f}{N_C + N_r} \times 100$$

In the business process, the following concepts are identified: lane, start event, end event, intermediate event, exclusive event, gateway, atomic activity, data object output,

10

association, sequence flow, and conditional sequence. These concepts and relationships are mapped 1-1 with the concepts and relationships identified in the integrating meta-model BPIMM, demonstrating that the meta-model can provide a valid representation of the business process model.

10.5.2. Evaluation of BPC-QC

An evaluation of the authority computation metrics is conducted in line with the measurement model introduced in Section 6.4.2 and based on the implementation reported in Section 10.4.

- Are the definitions of the metrics correct?

During the application, the definitions of authority metrics are found to be correct for this case and consequently there is no need for modification.

- Do they suffice?

During the application, the authority metrics are found sufficient for the computation.

10.5.3. Evaluation of BP-QC

Implemented in this case study, an evaluation of (a) BP-CQCF and algorithm, (b) business process patterns, and (c) computational formulae is conducted in line with the measurement model introduced in Section 6.4.2.

1) *BP-CQCF and algorithm*
    - Are the conceptual model and the method steps sufficient and effective for the purpose of computation?

BP-CQCF and algorithm are followed for the purpose of computation. The conceptual model and method steps are sufficient and effective in conducting the computation. As a result, there is no need for modification of the BP-CQEF and algorithm.

2) *Business process patterns*
    - Are the definitions of the business process patterns correct?

During the application, the business process patterns are found to be clear and consequently there is no need for modification.

- Do they suffice?

With regards to the structure of the business process model, the business process patterns are sufficient for decomposing the business process. As a result, there is no need for modification.

- Do all of the business process parts map 1-1 onto the proposed well-structured patterns?

All of the business process parts map 1-1 onto the proposed well-structured patterns.

3) *Computational formulae*
   - Are the computational formulae correct?

The proposed formulae for time computation are found to be correct. As a result, there is no need to change the definition of the computational formulae.

- Do they suffice?

The set of formulae is sufficient for computing authority in this case study. There is no need for adding new formulae for computing time.

10.6. Evaluation of the Approach by Individual Stakeholders

In this section, the measures on utility evaluation (Section 6.4.2) are revisited, capturing the views of stakeholders on the applicability, usability, and usefulness of the approach. To this end, the researcher conducts semi-structured interviews with the stakeholders to evaluate the utility of the case study. Opinions from three stakeholders are captured. Together, the stakeholders have more than 75 years of experience. The set of codes introduced in Chapter 6, Section 6.4.2, is the basis for data analysis of the interviews. The three sub-codes "Positive" (+), "Negative" (-), and "In Between" (+/-) represents the interviewees' opinions. Table 42 provides an overview of the interviewees' opinions for different codes.

Table 42 Overview of the interviewees' opinions on different evaluation codes

		Interviewees		
		D1	D2	D3
Codes	Relevancy of quality factors and dimensions for the business process	N/A	+/-	+/-
	Overall relevancy of quality factors and dimensions	+	+	+
	Adequacy of quality factors and dimensions	N/A	N/A	N/A
	Overall usefulness of the approach	+	+	+
	Overall usability of the approach	+	+/-	+/-
	Support required for implementation	+	+	+

A factual report is provided from the interview data, analysed by coding the data through the use of the ATLAS.ti 7.0 tool. Each statement in the report is accompanied by a closed parenthesis following this format: [#code of the interviewee: #Text Fragment Number in the transcript (T)] supporting the statement. Quotations from different stakeholders are separated by a "/" sign.

The outcome of this analysis with respect to the evaluation measures includes:

- Relevancy and adequacy of the quality dimensions and factors.
- Overall usefulness of the approach.
- Usability and support required for the implementation

The following sub-sections elaborate on each of the aforementioned measures. At the end a summary of the findings is provided.

10.6.1. Relevancy and Adequacy of the Quality Dimensions and Factors

Relevancy: The objective is to evaluate the relevancy of the quality dimensions and factors introduced in Section 4.3 for the investigated business process, as well as the overall relevancy of the dimensions and factors. The overall relevancy of quality dimensions and factors are reviewed during the interviews and are acknowledged by the interviewees [D1:T6/D2:T6/D3:T4,T5,T6,T7,T8,T11,T12]. With regards to the involvement of D1 in the "Bridge" project, the following factors and dimensions are highlighted as being of importance [D1:T6]: (a) throughput, timeliness and cost from the performance dimension, where cost is considered to be an important decision factor in workflow (i.e., business process) selection; (b) time efficiency is important; cost and resource are covered by the factor of cost from the performance dimension; (c) the availability dimension is important, however "time to shortage" is regulated by policies; (d) reliability; and (e) authority. Considering the interdependencies between different quality factors (e.g., time and cost), policies are required for prioritising quality considerations [D1:T6]. Besides, it is suggested to take into account the interdependencies between "cost" and "authority" factors [D1:T5] and "availability" and "authority" factors [D1:T2,T3,T4] in urgent situations in crisis management. It is maintained that the concept of urgency in "cycle time" and "timeliness" factors should be taken into account [D3:T20]. For SlimVerbinden, performance [D2:T2], efficiency [D2:T2], recoverability [D2:T2], availability [D2:T4/D3:T1] (of information in particular [D2:T2]), reliability [D2:T5/D3:T1], and authority [D3:T1] dimensions are considered important.

Adequacy: The objective is to evaluate the adequacy of the quality dimensions and factors introduced in Section 4.3, to examine whether a quality factor or dimension is missing from the list. A set of factors is mentioned as missing: (a) trust in sharing data [D2:T7/T26], (b) quality of coordination [D3/T15], (c) security and privacy of data [D1:T8], (d) quality of data [D1:T8], and (e) capability level of resources [D1:T8/T9] and their impact on the quality of following activities [D1:T9,T10,T11,T12]. However, the quantitative computation of these aspects is out of the scope of this thesis.

10.6.2. Overall Usefulness of the Approach

The overall usefulness of the approach is reviewed during the interviews. The overall usefulness is rated positively [D2:T19,T27/D3:21]. Factual and quantitative computation is valued [D1:T24/D2:T16/D3:T23,T24], as is the use of value of different quality factors for the entire business process or a branch [D1:T16/T19] with respect to the quality requirement at a specific point of time [D1:T19] and the option to select a suitable business process/branch with different alternatives [D1:T20,T27]. The approach fits the "workflow generation management" approach deployed in the Bridge project to compute the quality for the entire workflow or the entire relevant branches [D1:T27].

Involving stakeholders in the design workshops is similar to the serious gaming and effect-based solution approach [D1:T21]. The approach should consider the interdependencies and the effect of a change in one activity on the subsequent activities in the business process as the static nature of the approach is a concern [D1:T28,T29,T30]. The approach suggested to be extended to consider slack in the quality value of a branch while maintaining the expected quality value [D1:T32]. This extension is of importance to resource allocations in process executions [D1:T32].

The approach is considered of use for other business processes [D1:T40/D2:T20], for situations in which collaboration between different sectors is important (e.g., crisis management and traffic management) [D2:T21,T25,T27/D3:T24] and for situations in which there is a need for a mechanism to foresee the effect of dropouts, failure in connectivity, abuse of authorities, etc. [D2:T21,T25,T27]. In capacity planning for a collaboration method, having agreed and joint calculation methods is considered to be an advantage [D3:T29]. The applicability of the approach in this area is acknowledged [D3:T29].

10.6.3. Usability and Support Required for Implementation

The usability and support required for implementation is reviewed during the interviews. The overall usability of the approach is indicated [D2:T16,T17,T19], especially the estimation capability of the approach [D2:T19]. The approach is considered usable, provided it involves a fully automated environment [S1:T20] and software agents for implementation [D1:T22/D2:T22/D3:T25]. One the one hand, to bring the approach into production, software developers should understand the need for such quality computation [D2:T22], which demands a translation of the requirements of such a system to the experience of the developers [D2:T22]. On the other hand, end-users should be trained about usefulness of the approach [D2:T22/D3:T26]. The need for a road map is asserted, to identify the main mission for the computation, the relevant metrics, the data-gathering method, and the type of software required [D3:T25]. To enhance the usability, the software should be easy to use by semi-professionals [D3:T30]. For this reason, it is recommended to consider interaction design and affordances as well as simple modularisation of the software to be taken into consideration.

Considering the collaborative environment of crisis management, the need for a formalisation to conduct the computation collaboratively is highlighted [D1:T23]. The need for coming to mutual agreements about definitions and notions of quality between collaborative parties [D1: T23,T25,T26/D3:T21], in terms of standardisation [D2:T23] ontologies, taxonomies, and the maintenance of such ontologies and taxonomies is also indicated [D3:T21].

10.6.4. Summary of the Evaluation by the Stakeholders

Revisiting the evaluation measures introduced earlier in this section, a summary of the evaluation by the stakeholders is provided:

- **Relevancy and Adequacy of the Quality Dimensions and Factors:**

Relevancy: The overall relevancy of quality dimensions and factors are reviewed during the interviews and are acknowledged by the interviewees. That BP-QC does not include functionality specifying interdependencies between different factors in urgent situations in crisis management is a point of concern. For SlimVerbinden, performance, efficiency, recoverability, availability (information in particular), reliability, and authority dimensions are considered important.

Adequacy: A set of factors is mentioned as missing which is out of the scope of the thesis.

- **Overall Usefulness of the Approach:**

The overall usefulness is confirmed and conducting the computation quantitatively is appreciated. The BP-QC is considered to be useful to determine the value of different quality factors for the entire business process or a branch and to select a suitable business process or a branch on the basis of the quality requirement at a time. The static nature of the approach is regarded as a concern. Moreover, it is suggested that the approach can be extended by considering slack in the quality value of a branch while maintaining the expected quality value. The approach is considered useful to be deployed in the future for other business processes as well as collaborative environments.

- **Usability and Support Required for the Implementation:**

The overall usability of the approach is indicated, especially the estimation capability of the approach. The approach is considered usable, provided it involves a fully automated environment. The need for coming to mutual agreements about definitions and notions of quality between collaborative parties is highlighted. Moreover, to bringing the approach into production, software developers should understand the need for such quality computation and the end-users should be trained about the usefulness of the approach.

10.7. Chapter Summary

This chapter elaborates a case study conducted for a scenario from Organisation D. The context, the stakeholders, and their requirements are described. The case study encompasses (a) the evaluation of BPIMM, (b) authority computation at the concept level (BPC-QC), and (c) authority computation at the business process level (BP-QC). An evaluation of the findings is provided on effectiveness, based on the result acquired, and on utility, based on the feedback received from the stakeholders in interviews.

Chapter 11. Discussion of Case Studies

In science, "fact" can only mean "confirmed to such a degree that it would be perverse to withhold provisional assent." I suppose that apples might start to rise tomorrow, but the possibility does not merit equal time in physics classrooms.
-Stephen Jay Gould

11.1. Introduction

This chapter provides an analysis of (1) the Approach to Application and Validation (AAV), and (2) the applicability and validity of the research artefacts BPIMM, BPC-QC, BP-QC examined in four case studies described in Chapter 7 (Organisation A), Chapter 8 (Organisation B), Chapter 9 (Organisation C), and Chapter 1 (Organisation D).

This chapter is organised as follows. Section 11.2 conducts a discussion on AAV. Section 11.3 discusses the result of application and validation. Section 11.4 summarises the chapter.

11.2. Discussion of AAV

This section discusses the actions taken for purpose of case study rigour, the measurement model and data collection and analysis.

11.2.1. Case Study Rigour

The methodological guidelines defined by (Yin, 2003) are followed for the purpose of construct validity, internal validity, reliability and external validity of the case study conduct. For the purpose of *reliability,* a detailed case and interview protocols is used, documenting all procedures relating to the data collection and analysis phases of the study, and a structured database. The case study database is planned before data collection is initiated and maintained through the process (Yin, 2003). All relevant data such as audio records, interview transcripts, research memos, pictures from the design workshops, business process models, input data for computation, pictures of the notes taken in the workshops, interview notes etc., are maintained in the case study database (Yin, 2003, Miles and Huberman, 1994). The material is classified according to contexts (i.e.

organisations) and within each context according to the type of information (e.g. interview). For the purpose of *construct validity,* multiple sources of evidence are used to provide multiple data points for the same phenomenon, having key informants review the case study report to improve the accuracy of case study data, and establishing a chain of evidence so a reader can trace the results (Yin, 2003). In doing so, in every step of the evaluation process and specifically after each design workshop, a report is sent to the participating stakeholders to have their feedback on the results. Where possible, in the final stage of capturing stakeholders' feedback, other relevant business process stakeholders from different sections of the organisation are invited to give their feedback. For the purpose of *external validity* or extensibility of the findings, multiple case studies are conducted. For the purpose of *internal validity* data analysis techniques are deployed such as explanation building (Yin, 2003) and by matching the code extracted from the measurement model and the patterns found in the data (Miles and Huberman, 1994).

11.2.2. Measurement Model

A measurement model is introduced covering effectiveness and utility of the artefact. In this section, both aspects are discussed.

A set of measures for evaluating effectiveness of the implemented artefacts is provided. The measures are deployed consistently for all case studies where applicable. These measures are used for evaluating aspects sufficiency, effectiveness and correctness of the implemented artefacts. To extend AAV, more measures may be introduced covering other aspects of the artefacts. Furthermore, more evaluators may be involved in the effectiveness measurement.

Opinions of the stakeholders on the utility of the artefact are captured through interviews. Where applicable, opinions of the stakeholders are captured on utility of the implemented artefacts and the result of implementation. Furthermore, the opinions of the stakeholders on overall usefulness and the usability of the artefacts and support required for the implementation are captured. To extend AVV, more stakeholders may be involved and more aspects may be covered in the interviews if time have allowed.

11.2.3. Data Collection and Analysis

Three sources of data are used and analysed for the purpose of evaluation:

1) The data resulting from design workshops, namely: pictures from the notes of paper/whiteboard and the workshops' reports

After each workshop the outcomes of the workshop are sent in a report [1] to the workshop participants (i.e. stakeholders) asking for their feedback/approval, hence minimising the possible effect of the researcher on the report. The reports are used for the utility analysis.

2) The measured/estimated data provided by the stakeholders for the measurement purpose

The computations are conducted based on the data provided by the stakeholders. The outcome of the computation is communicated to the stakeholders for their feedback for the purpose of effectiveness evaluation. The outcome of the feedback/internal estimation is used for the utility analysis, hence minimising the possible effect of the researcher on the utility evaluation.

3) The interview transcripts

Coding is used for the analysis of the interview transcripts. Coding is conducted according a process (Miles and Huberman, 1994) for the purpose of soundness of the code assignment. For each case study, a report is provided on the analysis. Each line of the report is supported by a referral to the text fragment(s) of the transcript and the stakeholder(s) stated that line. To enhance the reliability of the findings, a senior researcher checks the interview transcripts, reports on coding and the final report. To extend AAV, more researchers may be involved in the analysis of the transcripts.

11.2.4. Procedure for Application and Validation

The scopes of the case studies are constrained by time, availability, and accessibility issues. Therefore, the generic procedure introduced could not be followed consistently in all four case studies.

11.3. Result of Application and Validation

In the following sections, the result of application and validation is examined for effectiveness and utility.

11.3.1. Effectiveness

This section discusses the "***effectiveness***" of the research artefacts (a) BPIMM: business process integrating meta-model, (b) BPC-QC: Business Process Concept Quality Computation, and (c) BP-QC: Business Process Quality Computation for the four case

[1] Appendix D: Workshop report template

studies described in Section 7.5, Section 8.4, Section 9.4, and Section 10.4. "***Effectiveness***" is evaluated for the set of measures listed in Section 6.4.2, namely: ***sufficiency***, ***effectiveness***, and ***correctness*** of the research artefacts.

➢ **Business Process Integrating Meta-Model (BPIMM)**

Each case study encompasses a unique business process. The evaluation measure is defined as the percentage of concepts and relationships of the model that can be mapped onto the concepts and relationships in the integrating meta-model. In all four case studies, one hundred per cent of the business process models are mapped onto the business process integrating meta-model, demonstrating that the meta-model can provide a representation of the models at hand. This confirms the ***effectiveness*** of the representational capability of the integrating meta-model as an abstraction of integrating concepts of seven mainstream business process modelling languages (BPMN, IDEF0, IDEF3, RAD, UML-AD, SADT, and EPC).

➢ **Computing the Quality of a Business Process Concept (BPC-QC)**

Concept quality computation is conducted in the case studies for Organisation A and Organisation D. The ***effectiveness*** of the approach relies on its building blocks namely, BPC-QEF, "quality factors", and quality metrics. All three are evaluated for Organisation A and quality factors metrics are evaluated for Organisation D.

i. ***Effectiveness*** *and* ***sufficiency*** *of Business Process Concept Quality Evaluation Framework (BPC-QEF) and algorithm*

BPC-QEF and algorithm have only been evaluated for one case study (Organisation A), providing insights in the relevant business process concepts, quality factors, and metrics, considering the stakeholders' requirements and objectives. The results show that BPC-QEF and the algorithm are ***sufficient*** and ***effective*** in the identification of concepts, factors, and metrics.

ii. ***Correctness*** *and* ***sufficiency*** *of quality factors*

The concept computation is conducted for both case studies for the quality factors "cycle time", "authority", and "failure frequency".[1] The definitions of these quality factors are considered to be ***correct*.** However, to enhance the ***sufficiency*** of the list, in one case study (Organisation A) there is a need to extend the definition of the "failure frequency" quality factor to also to cover failure frequency with respect to the number of failures relative to

[1] Note that not all of the quality factors and quality metrics this thesis distinguishes are applicable to these 2 case studies.

the number of executions. Moreover, in the same case study, a few new non-generic factors are introduced in response to the specific requirements of the stakeholders.

iii. ***Correctness*** *and* ***sufficiency*** *of quality metrics*

Computation of quality is conducted in three case studies for "cycle time", "authority", and "failure frequency". The definitions of these quality metrics are considered to be ***correct.*** However, to enhance the ***sufficiency*** of the list, in one case study (Organisation A) there is a need to extend the "failure frequency" quality metric to cover failure frequency defined as the number of failures relative to the number of executions, as mentioned above.

- **Computing the Quality of a Business Process (BP-CQ)**

Quality computation of a business processes is conducted for the case studies for Organisation A, Organisation B and Organisation D. To this end, BP-CQCF, business process patterns, and computational formulae are analysed:

i. ***Effectiveness*** *and* ***sufficiency*** *Business Process Compositional Quality Computation Framework (BP-CQCF) and algorithm*

BP-CQCF and its algorithm are deployed in three case studies. The conceptual model and method steps are considered to be ***sufficient*** and ***effective*** for the purpose of computation. As a result, there is no need for modification.

ii. ***Correctness, sufficiency*** *and* ***effectiveness*** *of the business process patterns*

Six patterns of sequential, parallel, exclusive, inclusive, simple loop, and complex loop are deployed for decomposition and computation purposes. To this end, the definitions of these patterns are considered to be ***correct***, and the patterns ***sufficient*** and ***effective*** for the decomposition of well-structured business processes. For Organisation D, all business process parts map 1-1 onto the proposed well-structured patterns. The business processes of Organisation A and Organisation B contain embedded patterns that do not map 1-1 onto well-structured patterns. The relevant business process models are restructured to make the mapping possible and subsequently to enable computation. The new parts are semantically equivalent to the original parts. Where needed, new probabilities are calculated.

iii. ***Effectiveness*** *and* ***sufficiency*** *of the computational formulae*

Computation of cycle time is considered for two case studies (Organisations A and B) and authority for one case study (Organisation D). In two of these case studies (Organisation A and Organisation D), the computational formulae are considered to be ***sufficient*** and ***effective*** for the purpose of estimation and measurement. However, for computation of cycle time in one case study (Organisation B), the formula for cycle time estimation is extended to take into account different "delay durations" associated with different probabilities before particular joints. This contributes to the ***effectiveness*** and ***sufficiency*** of the computational formulae.

11.3.2. Utility

"***Utility***" of the approach is evaluated for all four case studies in interviews with stakeholders. Over a period of six months (from April 2014 to September 2014), ten interviews are conducted with thirteen stakeholders (of which one is a group interview with four stakeholders) from six different organisations in four contexts (i.e., case studies). Stakeholders have different backgrounds and orientations (i.e., technology and management), with more than 236 years of experience in total and more than 154 years of experience working in their organisations, providing a great deal of insight about the "***utility***" of the approach.

Each case study has a different scope of implementation and validation, and therefore different measures are deployed for the evaluation. The following measures are deployed for evaluation of the approach by all stakeholders in all four case studies:

- Relevancy and adequacy of the quality dimensions and factors.
- Overall usefulness of the approach.
- Usability and support required for the implementation.

Table 41 provides an aggregation of the overview of the interviewees' opinions for different codes. As seen in Section 6.4.3, the three sub-codes "Positive" (+), "Negative" (-), and "In Between" (+/-) represent the interviewees' opinions. The numbers in the "result" column provide an overview of the overall opinion of stakeholders for different codes.[1]

[1] Please note that this table is not used for statistical-base conclusions from the qualitative outcome of the evaluation.

Table 43 Aggregation of the interviewees' opinions on different evaluation codes

		Interviewees													Overall result			
		Org. A		Org. B			Org. C					Org. D						
		A1	A2	B1	B2	B3	C1	C2	C3	C4	C5	S1	S2	S3	+	+/-	-	N/A
Codes	Relevancy of quality factors and dimensions for the business process	+/-	+/-	+/-	N/A	+/-	+/-	+/-	+/-	+/-	N/A	N/A	+/-	+/-	0	10	0	3
	Overall relevancy of quality factors and dimensions	+/-	+	+/-	+	+	+	+	N/A	N/A	N/A	+	+	+	8	2	0	3
	Adequacy of quality factors and dimensions	+	+	+/-	+/-	+	+/-	+	+	+	+	N/A	N/A	N/A	10	3	0	3
	Overall usefulness of the approach	+	+	+	+	+	+	+	+	N/A	+	+	+	+	12	0	0	1
	Overall usability of the approach	+	+	+/-	+/-	N/A	+/-	+/-	N/A	N/A	N/A	+	+	+/-	4	6	0	4
	Support required for implementation	+	+	+	+	+	+	+	N/A	N/A	+	+	+	+	11	0	0	2

11

The following paragraphs elaborate the aforementioned measures deployed for all case studies (Table 41), and the measures specifically deployed for the Organisation A case study:

- Ease of use, ease of learning, scalability and coherence of BPC-QEF and algorithm.
- Reliability of the measurement and estimation results.
- Improvement with respect to the current situation.

➢ **All case studies: Relevancy and Adequacy of the Quality Dimensions and Factors**

Relevancy: Each context studied in the case studies has a different mission and therefore a unique set of requirements (Dutch educational institution, a global financial institution, an international financial service provider, and national crisis management). The set of quality factors and dimensions are generic to the extent that the interviewees indicate their applicability for all of the case studies and other (future) business processes in the organisations/contexts. The quality dimensions and factors this thesis distinguishes in Chapter 4 are not all relevant to the business processes in these four case studies.

Adequacy: The overall adequacy of the quality dimensions and factors is indicated by the interviewees. Both Organisation B and D indicate a need for organisational specific quality dimensions and factors currently not included in the scope of this thesis scope. Organisation C indicates a need for "compliance" to be added to the list. This quality aspect is considered to be generic, and thus an important extension to the quality dimensions and factors distinguished in Chapter 4.

➢ **All Case Studies: Overall Usefulness of the Approach**

The overall usefulness of the approach to quantitative computation is indicated by the interviewees. The approach is considered to be applicable to other business processes and projects within the four organisations but also for business processes that mandate collaboration between different parties. Furthermore, several applications domains are mentioned for the approach.

Considering different aspects of quality simultaneously is maintained to be useful in providing a better view of a business process with which to determine relevant quality factors. Interviewees indicate that the approach can be used in the design phase, helping the process designers and analysts to think about what is relevant and important to be measured. The bottom-up approach in quality evaluation and its benefits to the organisation are highlighted.

The approach is found beneficial in providing useful insight about business processes for the purpose of improving them. Consideration of different levels of granularity and computation of a business process for quality computation is valued. The approach's consideration of different elements contributing to a quality value at the lowest level of granularity (e.g. cycle time: execution time, queue duration, and synchronisation time) is considered by interviewees to foster transparency at all levels. Interviewees also indicate that variations in the perception of a quality aspect at different levels should be taken into account.

- **All Case Studies: Usability and Support Required for the Implementation**

The usability and support required for implementation is reviewed during the interviews. The trade-off between accuracy and time is of importance. The approach is considered high-value and high-effort. Interviewees recommend automated support based on a formal design and template to extract data from databases. Such computation software should be user-friendly and easy to use, accompanied by a very easy user guide, practical examples, and a helpdesk. The need for flexibility of the evaluation system to facilitate changes in business processes is recognised.

The need for mutual agreement between collaborative parties about definitions and notions of quality is highlighted. Training, acceptance and support by all stakeholders (both technical and management oriented) is considered to be of utmost importance. Availability of data determines the choice of metrics for a business process. Other relevant aspects (e.g. organisational rules and structure) should be considered. The way data are deployed should be persistent within an organisation.

- **Organisation A Case Study: Ease of Use, Ease of Learning, Scalability and Coherence of BPC-QEF and Algorithm**

Ease of use, ease of learning, scalability and coherence are discussed along the lines discussed above. It is asserted that the approach for realising quality factors and metrics is easy to use, easy to learn, scalable and coherent.

- **Organisation A Case Study: Reliability of the Measurement and Estimation Results**

The results of both measurement and estimation with the data and estimations provided by the stakeholders are considered to be reliable.

- **Organisation A Case Study: Improvement with Respect to the Current Situation**

The approach pinpoints the few problems that were unknown. It is stated that the approach highlights the importance of business process design for the performance of a business process.

11.4. Chapter Summary

This chapter provides a discussion on the application and validation phase of the research, described in Chapter 6 to Chapter 1. The discussion is conducted in terms of effectiveness of the implemented research artefacts as well as utility of the approach according to stakeholders. To this end, the approach to application and validation (AAV) in Chapter 6 is revisited and the evaluation outcomes are discussed.

Part IV: Closure

Chapter 12. Conclusions and Outlook

Good design is a renaissance attitude that combines technology, cognitive science, human need, and beauty to produce something that the world did not know it was missing.
-Paola Antonelli

12.1. Introduction

The chapter concludes this thesis by providing an overview of the thesis, a summary of the contributions, a brief look at the limitations, and some insights into future research opportunities. The main research question is revisited in Section 12.1 and main contributions to answer the research questions are highlighted. In section 12.2, the research outcome in the design phase is positioned with regards to the criteria introduced in Section 2.1 for the evaluation of the current state-of-the-art. Moreover, the outcomes of the evaluation phase are discussed demonstrating the degree of ***utility*** and ***effectiveness***. As with any other research, this thesis faces limitations presented by the methods selected, the availability of organisations/stakeholders, researcher bias, and so on. These limitations and the efforts made to minimise them are presented in Section 12.3. This thesis also provokes more questions to be addressed during the subsequent research activities. These future research opportunities are presented in Section 12.4. Section 12.5 concludes this chapter.

12.2. Reprise

The thesis is motivated by the need for frameworks, algorithms, factors, and metrics for organisations to quantitatively compute the quality of their business processes at different levels of abstraction. The leading research question is:

Can quality of a business process be quantitatively computed at different levels of granularity?

The thesis employs a multi-method research design, rooted in design science and behavioural science based on post-positivism assumptions. During the design science phase, three research artefacts are designed and developed – BPIMM, BPC-QC and BP-QC - together with an approach AAV for their evaluation. AAV is used in four case studies for four business processes in four different contexts.

12.2.1. Design Phase

The contributions of this thesis include:

- **Integrating and Language-Independent Abstraction of BPMLS: BPIMM (Chapter 3)**
  - BPIMM, a business process integrating meta-model, is language-independent and provides multiple-source abstraction for concepts of mainstream BPMLs (business process modelling languages).
- **Computing Quality at the Lowest Level of Granularity: BPC-QC (Chapter 4)**
  - BPC-QEF and algorithm make it possible for business process modellers and analysts to measure quality of business process concepts (quality factors and metrics) in a systematic and generic manner. The framework establishes a set of conceptual structures and method steps, confined to neither a particular BPML nor a class of applications with a wide range of applicability.
  - A set of quality factors and dimensions for different business process concepts: activity, input, output, and event, covering different aspects of quality distinguishing six dimensions and thirteen factors.
  - A set of quality metrics enabling quantitative evaluation of the business process concepts against different quality factors.
- **Computing quality at a high level of granularity: BP-QC (Chapter 5)**
  - A conceptual framework and algorithm to assist business process modellers and analysts in computing the quality of (part of) a business process in a systematic and generic manner. The framework is neither confined to a particular BPML nor dependent on a certain class of applications.
  - A set of generic business process patterns to decompose business processes into more succinct parts.
  - A set of computational formulae for the given patterns and quality factors, to facilitate a quantitative quality computation of a business process.

Using the same criteria as those for evaluating existing approaches in the area of business process quality, the approach is formal, language independent, generic, quantitative, and systematic, while focusing on both high-level and low-level granularity. BPC-QEF focuses on the lowest granularity-level, namely business process concepts. BP-CQCF's focus is on high-level granularity, namely on (part of) a business process. In computing business process quality, BP-CQCF is systematic and provides a methodological means by which developers can measure the quality of business processes on the basis of the computational results of their constituent activities. In measuring the quality of individual concepts, BPC-QEF is systematic as it considers specific concepts found in mainstream BPMLs and subjects these concepts to an analysis according to defined quality dimensions, detailed quality factors, and metrics associated with them.

A design artefact is complete and effective when it satisfies the requirements and constraints of the problem it is designed to solve (Hevner et al., 2004). Considering the contribution of the thesis and positioning it with regards to the current state of the art, this thesis meets its original objective.

12.2.2. Application and Validation Phase

The outcomes of evaluation provide a view on ***effectiveness*** and ***utility*** of the approach.

The ***effectiveness*** of the business process integrating meta-model BPIMM is explored and confirmed in four case studies. The ***effectiveness*** of the proposed quality factors and metrics is enhanced by inclusion of an additional factor and metric **failure frequency** and an additional computational formula for **cycle time** to match the requirements of two of the four case studies. These extensions are not case study dependent. Revisiting the research objective specified in Chapter 1, the following ***effectiveness*** outcomes can be highlighted:

1) The effectiveness of ***frameworks*** and ***algorithms.***
2) The effectiveness of ***quality factors*** and ***metrics***.
3) The effectiveness of ***computational formulae***.
4) The effectiveness of business process patterns.
5) The effectiveness of quantitative computation of business processes at different levels of abstraction.

The findings on ***utility*** evaluation provide insight about the stakeholders' (users') point of view on applicability, usability and usefulness of the approach. With regard to the research objective specified in Chapter 1, the following opinions on the ***utility*** and usefulness of the approach are highlighted by the stakeholders:

1) Evaluation is conducted ***quantitatively.***
2) Ease of use, ease of learning, scalability and coherence of BPC-QEF ***framework*** and ***algorithm*** in specifying concepts, quality factors and quality metrics considering ***stakeholder requirements.***
3) Considering ***different levels of abstraction*** and bottom-up view in evaluation.
4) Relevancy and overall adequacy of ***quality factors.***
5) Reliability of ***computation*** results.

The findings confirm that, in the view of the stakeholders, the approach meets its objective.

12.3. Research Limitations

The purpose of this section is to indicate research limitations during the different stages of research. Mostly, these limitations are due to the scope, availability of resources, researcher bias, and time spent on the research.

12.3.1. Design phase

- **Epistemological Assumptions**

This thesis adopts post-positivist assumptions. This thesis could have followed other epistemological viewpoints such as interpretivism or critical realism. Also, it may be possible to conduct the research in the form of a multi-paradigmatic or meta-paradigmatic study. The constraints associated with the adopted paradigm are acknowledged, such as the possible effects of biases and the fact that theories, background, knowledge and values of the researcher influence what is observed.

- **Research Scope**
  - **Integrating and Language-Independent Abstraction of BPMLs: BPIMM**

In developing the business process integrating meta-model, this thesis investigates mainstream BPMLs, not all BPMLs. The business process integrating meta-model BPIMM that this thesis proposes is an abstraction of concepts of seven mainstream business process modelling languages (BPMN, IDEF0, IDEF3, RAD, UML-AD, SADT and EPC). Thus, its representational capability is limited to the expressive power of these languages. Moreover, the issue of semantic loss when a BPML is mapped onto the integrating meta-model is recognised.

  - **Quality Computation: BPC-QC and BP-QC**

First, the scope is on quantitative computation of the quality of a business process, and not on a qualitative evaluation. Moreover, the approach does not consider interdependencies between different quality factors (e.g., cost and time). The approach considers an individual instantiation of a business process for computation purposes and does not include several instantiations of a particular business process at a time. The approach relies on the given data for computation of the business process; credibility of the data and the accumulation of possible deviations in the data are not taken into account. The approach only considers business process models that are well-structured and well-behaved with regard to the current six patterns. Finally, the approach does not provide a formal approach to decomposition of overlapping and embedded patterns.

12.3.2. Application and Validation Phase

- **Case Study Selection and Scope**

The selection of the organisations for the case study is constrained by time, availability, and accessibility issues. All of the organisations are based in the Netherlands. More organisations, more interviews, different geographical regions, as well as incorporation of different sources of evidence (e.g., long term archival data) could have strengthened the insights obtained during this phase of research. Due to the specific requirements of the organisations and the business processes chosen, a full evaluation of the sixteen quality factors has not been achieved. As there is no tool support for the computations, the repeatability of the case studies is not straightforward.

- **Interview Conduct and Analysis**

Semi-structured interviews have a number of limitations (Robson, 2002a) of which a number also hold for this thesis (such as construct, internal and external validity as well as reliability), despite the explicit attention paid to mitigate these limitations and corroborate construct, internal and external validity, and reliability discussed in Chapter 11. The advantages of a group interview are in turn, limited by the downside of group interviews, namely that group dynamics and articulation of group norms might silence individual voices of dissent (Kitzinger, 1995).

12.4. Outlook

This thesis identifies directions for future research of which two are discussed below.

12.4.1. The Business Process Integrating Meta-Model: BPIMM

The business process integrating meta-model (BPIMM) can be deployed as a reference model for a comparative analysis of BPMLs. The representational capability of specific BPMLs can be compared using the meta-model to examine strengths and weaknesses of existing business processes and their integration. Moreover, BPIMM can be used as a basis to develop future BPMLs as well as to enhance existing BPMLs as it already provides an abstraction of the basic concepts of mainstream BPMLs. In addition, the meta-model can be extended to include concepts of other BPMLs. Finally, a method can be developed to evaluate the correctness of BPIMM and to empirically evaluate the theoretical ontological analysis of the business process meta-model.

12.4.2. Quality Computation: BPC-QC and BP-QC

Future work should explore the dependencies of quality dimensions, factors, and metrics. Moreover, existing industrial business process modelling tools (e.g., SAP, Pentaho, Oracle, and Tibco) can be enhanced with a simulation component and a workbench with which to analyse measured qualities. Other case studies are needed to evaluate the quality factors. Furthermore, strategic modelling approaches such as system dynamics can be coupled to business process modelling, using parametric definitions according to quality criteria, to experiment with 'what-if' scenarios. The approach can be extended to the area of collaborative business process management to capture and measure stakeholders' requirements at different levels of granularity. Besides, more patterns and related computational formulae can be included to enhance the expressiveness of the approach. In addition, the approach should be extended to provide a formal solution to compute overlapping patterns and embedded patterns. The concepts, factors, and measurement metrics can be defined formally, based on XES facilitating the modelling and computation for process mining purposes. Finally, the credibility of data and the accumulation of possible deviations of data can be considered in the computation.

12.5. Conclusion

To conclude, this thesis contributes to the body of knowledge in the field of business process quality. Many questions remain unanswered, and other approaches might be attempted by fellow researchers to further extend this body of knowledge. This thesis aspires to inspire other researchers to further this research.

THE END

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Appendix A: Information Sheet

Business Process Quality Computation

A study by Farideh Heidari

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Information Sheet

Research Description

The research concerns the development of frameworks, factors, and quantitative metrics for understanding and computing the quality of business processes. This leads to three major results: (a) the development of evaluation frameworks that are intended to assist process analysts to design business processes, (b) the identification of key quality factors relevant to business processes, and (c) the definition of metrics to quantitatively measure the quality of business processes. This research is being conducted at the System Engineering Section of TU Delft and is supervised by Prof. Dr. F.M.T. Brazier and Assistant Professor Dr. P.H.G. van Langen. The design part of the research is conducted. In the current phase of the research, the design artefacts are tested in real-life practical situations, resulting in empirical evidence of the added value of the research.

About this Interview

The main goal of this research phase is to evaluate the applicability of the research results. The approach outlined above is partially implemented within your organisation for a specific business process. On the basis of this case, the aim of this interview is to capture the views of stakeholders and case participants about the utility of the approach.

To guide the semi-structured interview, the researcher has derived a set of core questions, based on the implementation conducted in your organisation. While guided by these core questions, the interview will also allow for you to express your own views and concerns regarding the limitations of the approach. The interview is expected to take about 30-40 minutes.

Expected Benefits and Risks of Your Participation

While there is no direct benefit for you, your participation in this study is expected to lead to improvements of the approach, which you may want to implement within your organisation. Furthermore, you will receive first hand results of the study, made available through electronic means once this phase has been completed. There are no foreseen risks associated with your involvement in this study.

Audio Recording of Interviews

With your permission, the researcher would like to audio record the interviews for better data capture. You may wish not to have the interview recorded and still be able to participate in the project. Once transcribed, all audio files will be destroyed.

Confidentiality

All recordings and transcripts from interviews will be kept strictly confidential. Transcripts will be assigned a sequential number and no names will be entered to the study database. Furthermore, no one outside the researcher, the promoter and the supervisor will have access to the information you provide. In general, only aggregated results will be reported. While some individual responses may be reported, no individual will be identified within any of these responses.

Voluntary Participation

Participation in this study is purely voluntary. You may wish to withdraw your participation at any time, without penalty or judgment.

Questions / Further Information

If you would like to obtain additional information or if have any questions, please feel free to contact the research team members mentioned earlier.

Concerns / Complaints

If you have any concerns or complaints about the ethical conduct of the study, you may contact Professor Brazier on phone number 015 278 87529 or email F.M.Brazier@tudelft.nl.

Feedback

Feedback will be in the form of results of the study.

Thank you for your interest and cooperation.

Appendix B: Informed Consent Form

Business Process Quality Computation

A study by Farideh Heidari

Ph.D. Researcher
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Informed Consent Form

Statement of Consent

By signing below, you are indicating that you:

have read and understood the information sheet about this study;

had any questions answered to your satisfaction;

understand that if you have any additional questions you can contact the research team;

understand that you are free to withdraw at any time, without comment or penalty.

Please tick as appropriate

agree to participate in the study

And grant permission to audio record interviews

Name **Signature** **Date**

Appendix C: Semi-Structured Interview Protocol

Business Process Quality Computation

A study by Farideh Heidari
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Semi-Structured Interview Protocol

Commencing Interviews

<State appreciation for time taken to participate>
<Introduce yourself>
< Tell them the purpose of the interview, and tell them how you see quality, check if they have similar ideas on the concept>
<Check if consent to audio record, before recording>
<Begin>

Part 1: Background Information & Experience

1-1: How many years you are working?

1-2: How many years have you been working in technology related/Management positions[1]?

1-3: How many years you have been working for this department?

Part 2: Relevancy and adequacy of the quality factors and dimensions

A set of quality factors and dimensions were developed in the research. This list was introduced and discussed in the workshops. The interviewer provides the interviewee with the list to discuss the relevancy and adequacy of the quality factors and dimensions.

2-1: Which one of the quality factors and dimensions introduced was relevant to your requirements for this specific business process?

2-2: Which one of these quality factors you would like to see applied to the current future business processes?

2-3: Do you see any quality factor not included in the list of factors that you believe is important and should be added?

Part 3: Ease of use, and scalability of BPC-QEF and algorithm

A Quality Evaluation Framework and a corresponding algorithm were developed in the research for capturing the quality requirements, objectives and factors. This framework and algorithm were deployed in the workshops for this specific business process. The aim of this part is to examine the usability, usefulness and scalability of BPC-QEF and algorithm.

3-1: Was the approach for realizing the quality requirements, objectives and factors easy to use?

3-2: Was the approach for realizing the quality requirements, objectives and factors easy to learn?

3-3: Did you find the steps systematic to identify the quality requirements, objectives and factors?

3-4: Do you think the methodology employed for identifying and capturing the quality requirements and factors scalable for the bigger business processes?

Part 4: Reliability of the measurement and estimation results

The researcher measured the cycle time of 10 business processes and estimated its cycle time for 12 different scenarios. The results were presented to the interviewee and discussed in a workshop. The aim of this section is to examine the reliability of the measurement and estimation results.

4-1: Did you find the results of the measurement reasonable and according to your expectations?

4-2: Did you find the results of the estimation reasonable and according to your expectations?

Part 5: Overall usability and usefulness of the approach

The researcher uses this part for capturing opinion of the interviewee on the overall usability and usefulness of the approach

5-1: What was the overall gain from applying the approach?

5-2: Is the approach usable for your department?

5-3: Is the approach useful for your department?

5-4: Would you apply the approach to other business processes in your department?

5-5: What kind of support do you think you would need for the implementation?

5-6: Where do you see further applications of the approach?

<Provide opportunity for participant to comment on anything further>
<Thank the participant for their time and valuable responses>
<Note if participant would like copy of results (i.e. dissertation) and obtain contact details (Email or post)>

End of Interview

Appendix D: Workshop report

Workshop (#Number): (#Name)

Organisation: -----
Date: -----
Time: -----
Attendees:

- Farideh Heidari (TBM- TUDelft/ Researcher)
- #Stakeholder name
- #Stakeholder name
- …..

Workshop Goal
Action (steps) taken
Workshop Results
Agenda for the next workshop / to do list
Data of next workshop/ delivering the results
Appendixes
End of workshop report

Samenvatting (in Dutch)

Titel: Berekening van de kwaliteit van een bedrijfsproces

Subtitel: Het berekenen van non-functionele eisen om bedrijfsprocessen te verbeteren

Het modelleren van bedrijfsprocessen is een belangrijk onderdeel van systeemontwerp. Wanneer een bedrijfsproces wordt (her)ontworpen, specificeren de belanghebbenden de eisen waaraan dat proces moet voldoen, onderhandelen hierover en bereiken overeenstemming. Deze eisen omvatten non-functionele eisen ten aanzien van de kwaliteit van het proces. Dit proefschrift beantwoordt de vraag hoe de kwaliteit van een bedrijfsproces kan worden gespecificeerd en berekend, gegeven het model dat belanghebbenden gebruiken.

De motivatie voor dit proefschrift is het toenemende belang van de kwaliteit van bedrijfsprocessen. Als de kwaliteit van specifieke bedrijfsprocessen bekend is kunnen de belanghebbenden beoordelen of deze processen verbeterd moeten worden. Als ook de structuur en concepten bekend zijn waaruit deze processen zijn opgebouwd (met name gebeurtenissen, invoer, activiteiten en uitvoer), dan is het mogelijk een meer gedetailleerde analyse te maken van hun tekortkomingen en biedt dit een basis voor het ontwerp van verbeteringen.

De uitdaging van dit proefschrift is gegrond in de aanname dat organisaties behoefte hebben aan passende middelen om te kunnen bepalen of bedrijfsprocessen de doelen behalen waarvoor ze ontworpen zijn. Gegeven deze uitdaging is de hoofdvraag waarop dit proefschrift zich concentreert: “Kan de kwaliteit van een bedrijfsproces worden berekend op verschillende beschouwingsniveaus?” Het onderzoeksdoel is: “*Het ontwikkelen van een raamwerk, factoren en meetstandaarden voor het berekenen van non-functionele eisen (dat wil zeggen, kwaliteit) van bedrijfsprocessen op verschillende beschouwingsniveaus.*”

De belangrijkste uitkomsten van het onderzoek zijn:

1. BPIMM, een taalonafhankelijk meta-model om bedrijfsprocessen te integreren. Dit is gebaseerd op de concepten van zeven gangbare bedrijfsprocesmodelleertalen: BPMN, EPC, RAD, UML-AD, SADT, IDEF0 en IDEF3.

2. BPC-QC (Business Process Concept - Quality Computation), een aanpak om de kwaliteit van een bedrijfsproces op het laagste beschouwingsniveau te kunnen berekenen. Deze aanpak bestaat uit:

- BPC-QEF (Business Process Concept - Quality Evaluation Framework), een taalonafhankelijk generiek raamwerk met bijbehorend algoritme om de kwaliteit van concepten in een bedrijfsproces te berekenen: gebeurtenis, invoer, activiteit en uitvoer.

  a. Een verzameling dimensies en factoren die te maken hebben met de kwaliteit van een bedrijfsproces. De volgende kwaliteitsdimensies worden onderscheiden: performance, efficiency, betrouwbaarheid, herstelbaarheid, toelaatbaarheid en beschikbaarheid. Elke dimensie benoemt verschillende kwaliteitsaspecten door middel van factoren. Er is een niet-uitputtende lijst van zestien factoren opgenomen.

  b. Meetstandaarden voor elke kwaliteitsfactor, om de kwaliteit van een specifiek concept van een bedrijfsproces te kunnen berekenen.

3. BP-QC (Business Process - Quality Computation), een aanpak om de kwaliteit van een bedrijfsproces op het hoogste beschouwingsniveau te kunnen berekenen. Deze aanpak bestaat uit:

   a. BP-CQCF (Business Process - Compositional Quality Computation Framework), een taalonafhankelijk generiek raamwerk met bijbehorend algoritme om de kwaliteit van een bedrijfsproces als geheel te berekenen, gegeven de kwaliteit van de onderliggende concepten.

   b. Een verzameling generieke modelleerpatronen om een bedrijfsproces te splitsen in eenvoudigere onderdelen: sequentieel, parallel met synchronisatie, exclusief, inclusief, eenvoudige lus en complexe lus.

   c. Een verzameling van ruim honderd formules. Voor elke combinatie van een modelleerpatroon en een kwaliteitsfactor is een bijpassende formule om de kwaliteit te berekenen.

4. AAV (Approach to Application and Validation), een plan om BPIMM, BPC-QC en BP-QC in de praktijk samen met belanghebbende experts te kunnen evalueren. Dit plan bestaat uit een beschrijving van de meeteenheden, een meetmodel en een case study-procedure.

Om de toepasbaarheid van de uitkomsten van dit onderzoek te toetsen in de praktijk zijn er vier cases uitgevoerd in verschillende omgevingen: een Nederlands onderwijsinstituut, een wereldwijd financieel instituut, een internationale financiële dienstverlener en een Nederlands onderzoeksproject naar crisismanagement. In elk van deze case studies draaide het om een ander bedrijfsproces.

Dit proefschrift laat zien dat:

1. Een aanpak om de kwaliteit van een bedrijfsproces te berekenen kan worden ingezet onafhankelijk van de modelleertaal die gebruikt is om het bedrijfsproces te beschrijven.
2. Kwantitatieve kwaliteitsfactoren kunnen specifiek worden opgezet voor de concepten in een bedrijfsproces.
3. Kwantitatieve meetstandaarden en formules kunnen worden ontwikkeld voor specifieke kwaliteitsfactoren, waardoor verschillende kwaliteitsaspecten van een bedrijfsproces op verschillende beschouwingsniveaus van dat proces kunnen worden berekend.
4. Er kan een evaluatieplan worden ontwikkeld om de toepasbaarheid van de uitkomsten van dit onderzoek te evalueren (met name BPIMM, BPC-QC en BP-QC).

De uitkomsten van dit proefschrift zijn bedoeld bij te dragen aan de volgende vakgebieden: bedrijfskunde en management, requirements engineering, software engineering en bedrijfsprocesmodellering. Voor requirements engineering en software engineering zijn de uitkomsten bedoeld om in een vroeg stadium van het ontwikkelen van processen rekening te houden met non-functionele eisen. Op het gebied van bedrijfsprocesmodellering, informatiesystemen, service computing en cloud computing kunnen de uitkomsten worden gebruikt voor kwaliteit-gedreven modellering, ontwerp en herontwerp. Tot slot biedt het kennen van de kwaliteitswaarde van een bedrijfsproces op verschillende beschouwingsniveaus een basis voor verbetering van dit proces.

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About the Author

Farideh Heidari (1979) was born in Mashahd, Iran. She holds a bachelor degree in Mechanical Engineering of Agricultural Machinery from Ferdowsi University of Mashhad. Her BSc thesis titled "Investigating Physical and Mechanical Properties of Pistachio Nuts". Farideh holds a Master degree in Industrial Engineering from Sharif University of Technology in Iran, where she was involved in several research projects with industrial applications. Her master degree thesis titled "Analysis of Vendor Manage Inventory's Effect on Bullwhip Effect in Supply Chain" where she came up with a set of optimal supply chain strategies in response to different demand patterns through simulation. During her PhD studies, Farideh was involved in a few Dutch and European projects in Crisis Management where she applied her business process management knowledge. Her work has been published as journal papers, book chapters and in conference proceedings (seven in the area of business process management, three in the area of supply chain management, two in the area of crisis management, two in the area of e-learning, three in the area of agricultural machinery, one in the area of mechanical engineering and one in the area of human resource performance measurement). Farideh acted as a university lecturer and teacher in several universities. Besides research, Farideh has more than six years experience in industry in different roles such as R&D manager, business process developer/evaluator, engineering manager, system engineering expert, etc. In her free time, Farideh enjoys literature, socialising, travelling, visiting museums, trying and cooking international recipes, doing various sports, and solving puzzles. She enjoys the company of international people and getting to know different cultures.