Quality of business models expressed in BPMN

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ABSTRACT

Context. The quality of business process models is important in the area of model-based software development. The overall goal of this study was to develop and evaluate a model for assessing the quality of models (Process Diagrams) in Business Process Model and Notation (BPMN). The model was an instantiation of the developed metamodel that adopt ISO/IEC 1926.

Objectives. The objectives of the thesis were to propose, implement and evaluate a model for quality assessment of business process models in BPMN. The model was intended to help practitioners to check the quality of their BPMN models and provide meaningful feedback on whether the business process models are of good or bad quality. First objective was to develop a metamodel of models for quality assessment of business process models in BPMN, and later the model that in an instantiation of the metamodel. Within the model, the objectives were to propose the relevant quality characteristics, quality metrics, quality criteria and quality functions. Finally, usefulness of model for quality assessment of business process models in BPMN was to be evaluated.

Methods. The methodology was driven by essential elements of the model for quality assessment of business process models in BPMN. This is: quality characteristics, quality metrics, quality criteria and quality functions. In the beginning the metamodel of the model was developed based on the ISO/IEC 1926 standard. Later, in order to identify quality characteristics of models existing in the literature, a systematic literature review was conducted. Quality characteristics explicitly relevant to BPMN were compared against each other and selected. Overlapping quality characteristics relevant to BPMN were merged. Next, in order to obtain quality metrics that measure aspects of models of business processes, a literature review was carried out. The literature review was restricted by a proposed set of selection criteria. The criteria were questions that every relevant literature describing quality metrics must affirmatively answer in order to identify only metrics that were able to be assigned to identify quality characteristics. If the chosen quality metrics needed to be changed or adjusted for the sake of better results, the author added changes or adjustments and provided rationale for them. Next, in order to obtain quality criteria, values of the quality metrics were gathered through measuring a repository of BPMN models. The repository was gathered as a preparatory work for the thesis and it consisted of models of varying quality. Manual measurement of quality metrics for each BPMN model from the repository could not be done within a reasonable amount of time. Therefore, a tool to automatically calculate metrics for BPMN models was implemented. The quality criteria were proposed based on the results from interpretation of the values using statistical analysis. Later, quality functions that aggregate values of the metrics were proposed. The complete model was next integrated into the tool so that it could assess a quality of real BPMN models. Finally, the model for assessing the quality of business process models in BPMN was evaluated for usefulness through a survey and survey-based experiment.

Results. A metamodel of models for quality assessment of business process models in BPMN was proposed. A model for the quality assessment of models in BPMN was proposed and evaluated for usefulness. Initial sets of quality characteristics of models were found in the literature and quality characteristics that were relevant to BPMN were extracted. Quality metrics that measure aspects of models were found and adjusted to the BPMN notation. Quality criteria that state how values of quality metrics can be classified as good or bad were provided. Quality functions that state if quality characteristics are good or bad for a chosen BPMN model were provided. Finally, a tool that implements the model for quality assessment of models in BPMN was created.

Conclusions. The results of the survey and survey-based experiment showed that the proposed model for quality assessment of models in BPMN works in most cases and is needed in general. Additionally, the elements of the model which should be corrected were identified. Contacted users of BPMN expressed a will to use the suggested tool associated with the model for quality assessment of business process models in BPMN.

Keywords: model quality, business process modeling, BPMN, model-based software development
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1 **INTRODUCTION**

The chapter is structured as follow: **Section 1.1** provides the background and motivation, **Section 1.2** states the aims and objectives of the thesis, **Section 1.3** presents the posed research questions, **Section 1.4** describes the research methodology used and finally, **Section 1.5** outlines the thesis.

1.1 **Background and motivation**

Business processes are essential because they define the order of work, keep the competitive advantage, increase the quality and decrease maintenance costs (eg. Kluza et al. (2011)). Following Lindsay and Lunn (2003), business processes can become complex so that they are difficult to analyse, understand or explain. Due to the fact that business processes tend to grow larger and more complex with age, according to Muketha et al. (2010) they should be managed properly. Therefore, models of processes are used (eg. (Cardoso, Vanderfeesten & Reijers, 2010)).

Models play an important role in the entire software development process and working with models has become a common practice. As described by Khelif et al. (2009), business processes should be modelled because they can help in evaluating, improving and migrating to different technological platforms. There is also a growing need on the market to design and maintain models which support the full range and flexibility of most actual business needs (Drejewicz, 2012). Moreover, Drejewicz indicates that it is worthwhile to model business processes because it gives the possibility of estimating the effort related to the changes in the processes and/or their automation.

Due to the fact that modelling is getting more and more important, there is an increasing attention paid to the quality of models and the ways how they can be improved (Mohagheghi, Dehlen & Neple, 2009). The quality of models is claimed to have a positive influence on activities of effective software maintainability (Dubielewicz et al., 2012). This view is also shared in (Rolón et al., 2009). Also, Mohagheghi, Dehlen and Neple (2009) insist on improving the quality of models and claim that early detection (in models) and correction of defects reduces maintenance costs. Consequently, modellers should ensure that generated artifacts are correct and correctly built. Vanderfeesten et al. (2008) points out that effective modelling guidelines may lead to substantial economic benefits. Finally, Makni et al. (2010) admits that high quality business process models minimize design flows, avoid dysfunctions of the process once deployed and help in the understanding of the models.

In order to model business processes, various notations and languages are used, such as Business Process Model and Notation (BPMN), UML Activity Diagram, UML EDOC Business Processes, IDEF, ebXML BPSS, Activity-Decision Flow (ADF) Diagram, RosettaNet, LOVeM and Event Process Chains (EPCs). Among them, BPMN was currently established and got popularity as a notation to model business processes (eg. (Recker, 2008), (Aagesen & Krogstie, 2010)). The particularly interesting objective of the BPMN notation is that it was created in a way that it is readily understandable by all business users – business analysts, technical developers, and business people, while still being able to represent complex process semantics.
Additionally, BPMN notation is intended to bridge the communication gap between business process design and implementation (BPMN, 2011).

The focus of this Master Thesis is on developing and evaluating a model for assessing the quality of business process models in BPMN. The measurement of business process models is a relatively new discipline (Cardoso, Vanderfeesten & Reijers, 2010). Some metrics that measure BPMN models have been developed, for example the Control-flow Complexity metric (Cardoso, 2005) or Imported Coupling of a Process metric (Khlif et al., 2009). But in the literature the majority of existing metrics that allow to measure various aspects of models were originally suggested to measure, e.g. UML models (Unhelkar, 2005; Mohagheghi, Dehlen & Neple, 2009) or business processes modelled in the YAWL language (Gruhn & Laue, 2006a). The used metrics were taken and adjusted to the new purpose from software engineering, especially in object-oriented software engineering (e.g. (Khlif et al., 2009; Cardoso, Vanderfeesten & Reijers, 2010; Muketha et al., 2010)).

The initial literature search showed that there is no useful in practice model for assessing the quality of business process models in BPMN. This thesis project aims to develop and evaluate such a model. The project will also include implementing a plug-in to Business Process Visual ARCHITECT – a software tool for modelling in BPMN. The plug-in will be used in finding proper quality criteria that will be used in constructing an essential part of the model for assessing the quality of business processes models in BPMN.

1.2 Aims and Objectives

The aim of the thesis project is to **develop and evaluate a model for assessing the quality of business process models in BPMN**.

In order to meet the aim, the following objectives are defined:

- Develop a metamodel of models for assessing the quality of business process models in BPMN based on information from ISO/IEC 1926 standard.
- Develop a model for assessing the quality of business process models in BPMN.
  - Investigate (examine and review):
    - quality characteristics of models,
    - methods for measuring models.
  - Find out specific quality characteristics for business process models in BPMN.
  - Develop quality metrics for business process models in BPMN.
  - Propose quality criteria for business process models in BPMN.
  - Propose quality functions for business process models in BPMN.
- Evaluate the developed model for assessing the quality of business process models in BPMN.
1.3 Research Questions

To achieve the aim and objectives the following research questions will be addressed:

RQ1: What constitutes the metamodel of models for assessing the quality of business process models in BPMN based on ISO/IEC 1926 standard recommendations on software product quality?

RQ2: What constitutes the model for assessing the quality of business process models in BPMN?

RQ2.1: What quality characteristics of models exist?

RQ2.1.1: Which of the identified quality characteristics are suitable to the developing model?

RQ2.2: Which metrics are suitable for the constructed model?

RQ2.3: How to interpret the values of the chosen metrics?

RQ2.4: How to evaluate the quality of characteristics?

RQ3: Is the developed model for assessing the quality of business process models in BPMN considered as useful?

1.4 Research Methodology

1.4.1 Chosen Research Methodology

The main goal of the thesis was to develop and evaluate a model for assessing the quality of business process models in BPMN. This goal was achieved in several steps. The overall research methodology and details of the steps are presented in Figure 1.1, which provides the map used to guide the work. The figure should be read from left to right and from top to bottom. In the figure, coloured letters represent corresponding inputs and outputs of methods and activities. Additionally, coloured, bolded and underlined letters represent corresponding inputs and outputs of the elements of the model for assessing the quality of business process models in BPMN.
RESEARCH METHODS

Figure 1.1. Overview of Research Methods.
The research methodology that was applied was guided by the research questions. By executing the methodology, a number of outcomes were attained in order to answer the research questions. A summary of specific research methods used in each step of the thesis is presented in Table 1.1. The first main task was to develop a model (RQ2) that is an instantiation of the metamodel of models for assessing the quality of business process models in BPMN (RQ1). The construction of the model (RQ2) was guided by answering a number of sub-questions. After the model was built, the next main task was to evaluate the model (RQ3).

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Method(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1</td>
<td>ISO/IEC 1926 standard review</td>
</tr>
<tr>
<td>RQ2</td>
<td>Systematic literature review</td>
</tr>
<tr>
<td></td>
<td>(Kitchenham &amp; Charters, 2007)</td>
</tr>
<tr>
<td>RQ2.1</td>
<td>Literature review AND Defined selection criteria</td>
</tr>
<tr>
<td>RQ2.2</td>
<td>Statistical analysis</td>
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<tr>
<td>RQ2.3</td>
<td>Survey</td>
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<tr>
<td>RQ3</td>
<td>Survey AND Survey-based experiment</td>
</tr>
</tbody>
</table>

Table 1.1. Research questions and their corresponding methods.

1.4.1.1 Research method used in Step I (aimed to develop a metamodel)

In the beginning, the ISO/IEC 1926 standard was reviewed in order to examine what constitutes a metamodel of models for assessing the quality of business process models in BPMN. The standard recommendations on software product quality allowed to develop the metamodel (see Section 3.4).

1.4.1.2 Research methods used in Step II (aimed to develop a model)

The model for assessing the quality of business process models in BPMN is an instantiation of the developed metamodel. It is built of four main elements: quality characteristics, quality metrics, quality criteria and quality functions.

Firstly, in order to find out what quality characteristics of models exist, the systematic literature review (SLR) method was used (Kitchenham & Charters, 2007). As a result of conducting the SLR, a set of the characteristics identified from the literature was obtained (RQ2.1, see Section 4). Characteristics explicitly relevant to BPMN (RQ2.1.1, see Section 4) were extracted from the characteristics found in the SLR.

Then, in order to identify quality metrics that can measure aspects of models of business processes (RQ2.2, see Section 5), identification and selection of metrics was conducted. For identification of metrics a literature review was performed. In order to select the relevant metrics, a set of selection criteria was proposed by the author of the thesis. The selection criteria determined whether the metrics identified in the literature review were useful, well defined and relevant. The selected quality metrics were adjusted (when necessary) to become relevant for BPMN.

Next, to interpret values of the quality metrics, quality criteria were proposed (RQ2.3, see Section 7). Quality criteria are functions that indicate whether the result of the quality metrics is good or bad. The criteria were obtained by examining
a repository of existing BPMN models (see Section 6.1). The repository was already gathered as a preparatory work for the thesis and it consisted of models of varying quality obtained from different sources. Manual measurement of metrics for each BPMN model from the repository could not be done within a reasonable amount of time (see Section 6.2). Therefore, a tool to automatically calculate metrics for BPMN models was implemented (see Section 6.3). The results from the tool were collected and clustered statistically in order to understand the range, distribution and overall trend of results. Quality criteria were proposed based on the results of the clusterization.

In the model for assessing the quality of business process models in BPMN, quality functions must have been assigned to the chosen quality characteristics (RQ2.4, see Section 8). Quality functions determine whether a specific quality characteristic is of good or bad quality. The quality functions that aggregate quality criteria were proposed and used priorities of sub-characteristics obtained from the survey (see Section 8.3). Later, quality functions were integrated into the tool implementing the complete quality model for assessing the quality of business process models in BPMN (see Section 6.4).

1.4.1.3 Research methods used in Step III (aimed to evaluate a metamodel)

In order to evaluate the usefulness of the proposed quality model for assessing the quality of business process models in BPMN (RQ3, see Section 10), a survey and a survey-based experiment were conducted. Participants of the survey were experts (people who have experience in the field of BPMN models) as well as students who are learning about BPMN and students who have knowledge about other than BPMN notations for modelling business processes.

1.4.2 Suitability of Research Methodology

Four major methodologies in thesis were selected. These were systematic literature review, literature review, survey and survey-based experiment. The author of the thesis has described the reasons for choosing the methodologies in Section 1.4. The aim of this section is to discuss the suitability of the chosen research methods in comparison with common alternatives.

The author chose to use a review of the ISO/IEC 1926 standard in order to answer RQ1 and a systematic literature review (SLR) as defined by Kitchenham and Charters (2007) in order to answer RQ2.1 and RQ2.1.1. The research questions ask for what quality characteristics exist (RQ2.1) and which are applicable to BPMN (RQ2.1.1). The author of the thesis could have chosen a number of methodologies in order to answer these research questions including using systematic mapping or interviews to elicit the answers.

A systematic mapping as defined by Petersen et al. (2008) differentiates itself from a systematic literature review by focusing on providing, “(…) a structure of the type of research reports and results that have been published by categorizing them and often gives a visual summary, the map, of its results” (Petersen et al., 2008). The coarse grained analysis which a mapping provides would not have met the needs of the thesis since a structuring would not have been enough to cope with the multiple sets of quality characteristics already proposed. As a result, the author of the thesis chose to conduct a SLR as it would enable the preparation of, “(…) a framework/background in
order to appropriately position new research activities” (Kitchenham & Charters, 2007). As a result, by using an SLR the author of the thesis was able to summarize the existing quality characteristics and propose a systematization of them as the background for the thesis.

Secondly, interviews could be considered a reasonable choice for bringing insight to what quality characteristics are important in modelling and specifically in BPMN. However, given the existing body of research on quality characteristics the author of the thesis chose to rely on peer-reviewed scientific literature as a basis for the thesis instead.

As an alternative to the literature review, the author of the thesis could have conducted a systematic literature review on BPMN metrics. In this case, a systematic literature would have allowed for the repeatable identification of metrics. However, given that there was already a systematic review done (González et al., 2010), and the author of the thesis had a systemized set of quality characteristics. A literature was chosen that was guided by selection criteria proposed and with the help of the existing systematic review of González et al. (2010).

In order to understand how experts assess the quality of business process models in BPMN, the author of the thesis chose to use a survey. As an alternative, interviews could have been used. By using interviews more in depth insight and qualitative feedback could be gathered based on discussion during the interview. The author of the thesis however wanted to use the results of the experts to later conduct an experiment and so the choice was made to use a survey. A survey allowed for more quantitative feedback, and additionally the survey was sent out in a way that experts could leave further comments if they wanted to. The choice to use a survey was thus a result of the need for quantitative data from experts that could be generalized and used later in the thesis.

Finally, using a case study as an alternative to a survey-based experiment was considered. A case study is defined by Yin (2002) as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”. In general, cases studies are helpful in situations where it is unclear what is under investigation. However, case studies are not relevant in this thesis since only metrics and quality characteristics that are well defined and implemented in a tool are assessed. Moreover, case studies are not helpful when there are clearly defined hypothesis that will be tested as seen in this thesis.
1.5 Outline of Thesis

The remaining parts of this document are structured in sections with different concerns:

**Section 2** introduces the basic terms and concepts used in the thesis. These are business processes, models and modelling and BPMN representation.

**Section 3** discusses the problem of quality. Definition of quality and quality model is provided. Additionally, a metamodel of models for assessing the quality of business processes models in BPMN is defined.

**Section 4** using the results of the systematic literature review (Kitchenham & Charters, 2007), summarizes quality characteristics and sub-characteristics for business process models in BPMN.

**Section 5** focuses on the identification and selection the metrics to measure aspects of models of business processes.

**Section 6** describes both the repository of BPMN models that was gathered as a preparatory work for the thesis and the implemented tool and its importance.

**Section 7** proposes quality criteria that interpret values of the quality metrics.

**Section 8** proposes quality functions that determine whether a specific quality characteristic is of good or bad quality.

**Section 9** groups together the previously developed parts of the model for assessing the quality of business process models in BPMN into a complete model.

**Section 10** evaluates the model for assessing the quality of business process models in BPMN with the use of the survey and survey-based experiment.

**Section 11** discusses limitations and threats to validity.

**Section 12** describes future research and concludes the paper.

**Section 13** lists references.

**Appendix A** lists results of the systematic literature review.

**Appendix B** provides evidence of (sub-) characteristics based on the literature.

**Appendix C** describes details of models from the repository of BPMN models.

**Appendix D** lists results of measures of BPMN models from the repository.

**Appendix E** includes the survey.
2 BASIC CONCEPTS

This section provides a short overview on the concepts important for this thesis: business processes, models and modelling and BPMN representation.

2.1 Business processes

Processes may be classified differently. For example, Lindsay and Lunn (2003) distinguish between production processes and office processes. They also provide division of processes into material processes, information processes and business processes. Lindsay and Lunn (2003) say that some researchers distinguish office processes from processes executed by machines, and additionally, production processes can be distinguished from coordination processes. This paper considers only business processes. The following are definitions of business processes:

1. A **business process** according to the BPMN specification is “a defined set of business activities that represent the steps required to achieve a business objective. It includes the flow and use of information and resources.” (BPMN, 2011)

2. “A **business process** is a set of coordinated activities that are performed either by humans or by tools with an objective to realize a certain business result” (Pant & Juric, 2008).

3. A **business process** can be shortly defined as: “the set of internal activities performed to serve a customer” (Lindsay & Lunn, 2003).

4. A **business process** can be generally defined as: “set of partially ordered activities intended to reach a goal” (Lindsay & Lunn, 2003).

5. A **business process** can be defined as: “a sequence of activities which transform inputs into outputs” (Lindsay & Lunn, 2003).

6. “A **business process** is a collection of activities that takes one or more kinds of input and creates output that is of value to the customer” (Lindsay & Lunn, 2003).

Business processes define the order of work. Efficient business processes include only necessary activities and can improve or speed up the work of companies. Business processes can help to reduce the development costs (launch software on time within budget), increase the quality, decrease maintenance costs, etc. Therefore, business processes are essential in every company, regardless of its size. Working with process oriented structures is the solution for organizations to keep the competitive advantage and to be ready to response to the needs of business environment (Lindsay & Lunn, 2003). According to Pant and Juric (2008) there are two big challenges for managing business processes in industry:

1. every company has unique business processes,
2. business processes are not constant but evolve over time.

Business process should be managed properly. For example, Muketha et al. (2010) described that business processes tend to grow larger and more complex with age, (what is undesirable and must be controlled), highly complex processes are error-prone, difficult to understand and hard to maintain.

Main stakeholder’s needs for business processes based on the literature:

- the need for improving the quality of business processes (Cardoso et al., 2006),
the need for identifying weaknesses of business processes (Heravizadeh, Mendling & Rosemann, 2008) and avoiding errors (Cardoso et al., 2006),
the need for decreasing the risk of creating systems that might not meet the posed requirements (Kluza et al., 2011),
the need for understanding business processes – how the process is defined, who is involved in the various related activities and how long it takes to execute the process (Pant & Juric, 2008),
the need for improving, maintaining, modifying and managing business processes, (Pant & Juric, 2008), (Cardoso et al., 2006) and (Vanderfeesten et al., 2007),
the need for analysing business processes (Cardoso, Vanderfeesten & Reijers, 2010),
the need for standardization in representing business processes (Lindsay & Lunn, 2003),
the need to contain only needed activities (Lindsay & Lunn, 2003),
the need for adapting business processes to new/improved aspects or to the increasingly changing environment (Lindsay & Lunn, 2003),
the need for automated business processes (Makni et al., 2010) or (Drejewicz, 2012),
the need for reusability of business processes (Thammarak, 2010),
the need to satisfy demands of the customers (Heravizadeh, Mendling & Rosemann, 2008),
the need for flexibility of business processes (Pant & Juric, 2008),

This list should also be expended by two elements proposed by the author of the thesis: the need for documenting business processes and the need for comparing business processes against each other.

Stakeholder’s needs for business processes (see the list above), have a reflection in needs posed for business process models. The needs are then reflected in the quality characteristics expected to be fulfilled by the models, which could be described as having a high quality. This will be further explained in the next sections.

2.2 Models and modelling

2.2.1 Business process modelling and models

According to Reijers, Mendling and Recker (2010), the process modeling discipline has been an active area with a history dating back to 1992 and has been the central approach to Business Process Management (BPM).

Nelson and Monarchi (2007) describe modeling as a multi-step transformation from the real word to an implementation. The traditional approach of modeling situates a process in a chain between input and output (Lindsay and Lunn, 2003). Through modeling, models (diagrams, sketches) are provided. Mohagheghi, Dehlen and Neple (2009) consider models as the primary software artefact. Following (Lindsay & Lunn, 2003), “models are simplifications in order to bring clarity and understanding to some aspect of a problem where there is complexity, uncertainty, change or assumptions”. Models in BPMN can visualise business processes and show how they function. Business process models in BPMN can describe various aspects of processes e.g.
control flow, exchange of documents, used resources and responsibilities (Gruhn & Laue, 2006).

White (2004) define “a Business Process Model (...) is a network of graphical objects, which are activities (i.e., work) and the flow controls that define their order of performance”.

The purpose for which a business process model in BPMN is developed is very important. Business process models are used for example in software process improvement, enterprise modeling, active knowledge modeling as well as quality management (Krogstie and Sølvberg, 2000). Kluza et al. (2011) explained that the model of business processes is intended to help organizations to reflect their mode of operation, which subsequently will reduce the risk of creating systems that might not meet the posed requirements.

Some examples where models of business processes are commonly used:
- to develop software (Reijers, Mendling & Recker, 2010; Vanderfeesten et al., 2008),
- to aid in various management initiatives (Sánchez-González et al., 2010),
- to provide a base for trainings (Vanderfeesten et al., 2008),
- to estimate costs and budgets (Vanderfeesten et al., 2008),
- to improve and/or modify business processes (Makni et al., 2010),
- to identify bottlenecks (Pant & Juric, 2008),
- to detect defects early (Rolón et al., 2009),
- to minimize design flows (Makni et al., 2010),
- to understand business processes (Heravizadeh, Mendling & Rosemann, 2008),
- to reveal weaknesses of business processes (Heravizadeh, Mendling & Rosemann, 2008),
- to visualise business processes (Reijers, Mendling & Recker, 2010),
- to optimize business processes (Pant & Juric, 2008),
- to automate business processes (Cardoso, 2005),
- to standarize (Rolón et al., 2009) business processes in a company,
- to document business operations (Sánchez-González et al., 2010),
- to improve customer satisfaction (Reijers, Mendling, Recker & 2010),
- to ease the communication between stakeholders (Reijers, Mendling & Recker, 2010),
- to ease the process of the flow of the informations between different stakeholders (Vanderfeesten et al., 2008),
- to obtain a tool for a brain-storming (Heravizadeh, Mendling & Rosemann, 2008),
- etc.

Additionally, the author of the thesis would include to this list also two reasons: to hide technical details and to provide abstractions.

2.2.2 BPMN modelling and models

In order to model business processes, various notations and languages are used. Reijers, Mendling and Recker (2010) indicate that business processes are often modelled using a graphical language to represent process flows, roles (actors and systems) and related documents. Examples of notations for modelling business
processes are: Business Process Model and Notation (BPMN)\(^1\), UML Activity Diagram\(^2\), UML EDOC Business Processes\(^3\), IDEF\(^4\), ebXML BPSS\(^5\), Activity-Decision Flow (ADF) Diagram\(^6\), RosettaNet\(^7\), Line of Visibility Engineering Methodology (LOVeM)\(^8\), or Event-Process Chains (EPCs)\(^9\).

Additionally, there is a UML Profile for BPMN Processes (BPMNProfile)\(^10\). BPMNProfile, which provides a mapping between UML and BPMN, recently released by OMG as a beta version in May 2013. This thesis (and its research) originally began well before the release of this “in process” BPMNProfile standard. As the status of the standard indicates, BPMNProfile has not yet been released as a formal specification, and so the more mature and formalized BPMN standard was chosen to be used in this thesis.

Other profiles also exist, for example, there is an additional BPMN profile for the Unified Profile for Department of Defence Architecture Framework and UK Ministry of Defence Architecture Framework (UPDM)\(^11\), which is focused on making UPDM compliant for BPMN modeling in a military context. Since the goal of the thesis was not to provide a model for the quality of business process models in BPMN in a military context, this profile of the standard was not used.

An important characteristic of all profiles which are created for BPMN is that they seek to make a separate modeling language, e.g. UML, compliant with the original BPMN standard. As a result, the author of the thesis chose a well-known BPMN standard, and did not use any of the other profiles.

In this thesis BPMN is used. The BPMN was developed and suggested as a standard notation by Object Management Group (OMG). The current OMG formally released version of BPMN is version 2.0\(^12\) (launched in January 2011) therefore this version was chosen in the thesis. The first version BPMN 1.0 was released in 2004; however the final adopted specification of BPMN 1.0 was finalized in 2006. BPMN is since then no longer considered as a new area and has been already evaluated both empirically and analytically (Aagesen & Krogstie, 2010).

The reasons why BPMN was chosen in the thesis are as follows.

1. BPMN is currently a widely used notation to model business processes (e.g. (Recker, 2008), (Aagesen & Krogstie, 2010)).
2. The BPMN notation is intended to bridge the communication gap between business process design and implementation (BPMN, 2011).

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\(^{1}\) The specification for BPMN is available in: [http://www.bpmn.org/](http://www.bpmn.org/)


\(^{3}\) UML Profile for enterprise distributed Object Computing (EDOC) is available in: [www.omg.org/technology/documents/formal/edoc.htm](http://www.omg.org/technology/documents/formal/edoc.htm).

\(^{4}\) IDEF family of methods is available in: [http://www.idef.com/](http://www.idef.com/).

\(^{5}\) ebXML BPSS technical specification is available in: [http://www.ebxml.org/specs/ebBPSS.pdf](http://www.ebxml.org/specs/ebBPSS.pdf).


\(^{8}\) LOVeM methodology: [http://publib-b.boulder.ibm.com/redbooks/redbooks.nsf/0/8a312ab5a7d83xd8525659d002c556b](http://publib-b.boulder.ibm.com/redbooks/redbooks.nsf/0/8a312ab5a7d83xd8525659d002c556b).

\(^{9}\) EPC method developed within the framework of ARIS: [http://www.ariscommunity.com/event-driven-process-chain](http://www.ariscommunity.com/event-driven-process-chain).

\(^{10}\) The specification for BPMNProfile is available in: [http://www.omg.org/spec/BPMNProfile/](http://www.omg.org/spec/BPMNProfile/).

\(^{11}\) The specification for UPDM is available in: [http://www.omg.org/spec/UPDM/](http://www.omg.org/spec/UPDM/).

\(^{12}\) The current version of BPMN can be found at: [http://www.omg.org/spec/BPMN/Current](http://www.omg.org/spec/BPMN/Current).
3. The particularly interesting feature of the BPMN notation is that it was created in a way that it is readily understandable by both business analysts, technical developers and business people, while still being able to express complex process semantics (BPMN, 2011).

The BPMN specification defines the notations and semantics of Collaboration Diagrams, Process Diagrams and Choreography Diagrams. However, the focus of this thesis is to develop and evaluate a model for assessing the quality of models (Process Diagrams only) in BPMN.

2.2.3 Quality models

Definitions of quality model based on the literature:

1. “A set of quality goals (also called quality attributes or quality characteristics in the literature) and their relations, accompanied by a set of practices or means to achieve the quality goals, evaluation methods for evaluating quality goals and links to related literature” (Mohagheghi, Dehlen & Neple, 2009).

2. The “defined set of characteristics and relationship between them, which provides a framework for specifying quality requirements and evaluating quality” (ISO/IEC 25000, 2005).

The definitions put forth that quality is the result of defining a practice or defining the relation of characteristics for how a model should be created. The model creation is then followed by evaluations, as recognized by both definitions.

2.2.4 Nomenclature used in the thesis

In this thesis the term ‘model’ will be used in three contexts:

1. In the general context of business process models. For business process models there are a number of informal and formal approaches, notations or methodologies. For example, UML Activity Diagrams, UML EDOC Business Processes, IDEF, ebXML BPSS, Activity-Decision Flow (ADF) Diagram, RosettaNet, LOVeM, or Event-Process Chains (EPCs).

2. In the context of business process models which use Business Process Model and Notation (BPMN) (BPMN, 2011), here the author of the thesis will clearly identify them as BPMN models or models in BPMN.

3. In the context of the quality model; here a quality model is used to measure and assess BPMN models (for more details see Section 3.4). While talking about the model for assessing the quality of business processes models in BPMN, the full name or the abbreviation MAQ will be used.
3 PROBLEMS OF QUALITY

This section discusses the problems of quality and addresses the questions of how to assess the quality of business process models in BPMN and what the quality of the BPMN model consists of.

3.1 Introduction

The term ‘quality’ is very general. In the literature, it is defined from multiple perspectives and described from different points of view, in various ways. Through many years numerous informal and formal definitions have been provided. Additionally, definitions of quality usually differ depending on the chosen context. Besides this, in the literature one can find many descriptions of the expectations on quality and what it describes or what it represents. The expectations may be additionally different for different people, may change and/or evolve over time or may not be consistent between projects or areas. For example, it is possible that one stakeholder will estimate the same business process model in BPMN as having a high quality, while the other can show that quality of the model is inadequate and the third may argue that it is sufficient. The arising problem is the question when can one be sure that the model has reached the right level of quality?

The next problem is that different users’ perspectives may be specified and for each user perspective quality can be described or characterized individually. In the opinion of the author of the thesis, there is no single best definition of quality due to its invisible nature. Therefore, definitions can only clarify descriptions or increase the level of detail as to what the quality is.

It is worth to consider the fact, that the individual's assessment of quality depends on the point of view of the evaluator and the aspects that are the most important for him or her. Hofman (2008) points out that it is not easy to precisely understand the needs of the stakeholders, in the way that one will have the unambiguous possibility to calculate the level of their satisfaction. Furthermore, he indicated that all models are only the approximation of reality because the needs themselves are not homogeneous.

Based on conducting literature review, the need for achieving a high quality of BPMN models is undeniable and can be supported by many arguments both industrial-based and research-based. The identified arguments why the quality of business process models is important are as follows:

- High quality of models help in understanding and maintaining of the business process (Reijers, Mendling, Recker, 2010; Khelif et al., 2009; Sánchez-González et al., 2010).
- The quality of models is claimed to have a positive influence on activities related to effective software maintainability (Dubielewicz et al., 2012).
- Improving the quality of models can help in reducing maintenance costs (Mohagheghi, Dehlen & Neple (2009).  
- Highly complex processes are error-prone, difficult to understand and hard to maintain (Muketha et al., 2010).  
- Improving the quality of models can help in early detection (in models) and correction of defects (Mohagheghi, Dehlen & Neple (2009). Especially if the detection will be automatic. Due to the fact that the early discovery
of defects in software artefacts is cheaper, modellers should ensure that generated artefacts are correct and properly built. As described in (Reijers, Mendling & Recker, 2010), business process models with errors bring consequences in later design phases, e.g. flows which are easy to correct in early stage of the design, become increasingly expensive with the progression of a project. Reijers, Mendling and Recker (2010) warn that the error rate of process models is quite significant and even equals 10-20%.

- Poor quality of BPMN models can result in software systems that do not satisfy user needs. This is because poor quality of process models can cause poor quality software requirements resulting in a poor information system (Rozman, Polancic & Horvat, 2007).
- Modeling guidelines for quality may lead to substantial economic benefits (Vanderfeesten et al., 2008).
- Correct models help to provide adequate quality assurance (Sánchez-González et al., 2010).
- High quality business process models minimize design flows and avoid dysfunctions of the process once deployed (Makni et al., 2010).
- Automated detection of the level of quality of models may help because modellers are often non-experts (Sánchez-González et al., 2010) and have just a brief starter training and little or no experience (Reijers, Mendling & Recker, 2010).

### 3.2 Definition of quality

Definitions of quality are formally defined in a number of norms and standards, such as ISO standards (International Standards Organization), SPC (Statistical Process Control), SQC (Statistical Quality Control), TQM (Total Quality Management), Six Sigma, etc. Several researchers also proposed different frameworks to quality assurance and control. For instance, SEQUAL – Semiotic Quality Framework (Krogstie, Sindre and Joergensen, 2006) or QoBP framework (Heravizadeh, Mendling & Rosemann, 2008).

The majority of the existing definitions of quality seem to rely mostly on the intuition of readers. Hofman (2008) suggested that existing definitions of quality are too general, which leaves a place for uncertainty and the need for semantic analysis. Moreover, Kan (2006) indicates that quality can be considered, felt and judged but not weighed or measured.

In this thesis ISO/IEC 9126 (2001) is used as the base for the metamodel (see Section 3.4). Therefore, the ISO/IEC 9126 (2001) definition of quality is the most precise for this thesis. Other quality definitions exist, three examples are given below.

The definition of quality by PMBOK is the most similar to ISO definition.

**ISO/IEC/IEEE standards**

ISO International Standards ensure that products are of good quality. In the field of computer science two sets of quality norms were proposed. The latest developments with the ISO/IEC 25000 SQuaRE series of standards is aimed to replace the older norms: ISO/IEC 9126 (2001) and ISO/IEC 14598.

Basing on ISO/IEC 9126 (2001), quality is defined as “the totality of characteristics of an entity that bear
on its ability to satisfy stated and implied needs”. Similarly, in ISO 9000 (2005) quality is defined as a “degree to which a set of inherent characteristics fulfils requirements” where a requirement is defined as a “need or expectation (...)”. According to the ISO/IEC/IEEE 24765 (2010), a quality is described as an “ability of a product, service, system, component, or process to meet customer or user needs, expectations, or requirements”.

Additionally, in IEEE Standard 610.12 (1990) quality is described as “the degree to which a system, component or process meets specified requirements”.

**PMBOK (2004):** In (PMBOK, 2004), a general definition of quality can be found. A quality is “the degree to which a set of inherent characteristics fulfils requirements”.

**Quality by Crosby:** Crosby (1980) defined quality as the “conformance to requirements (...)”.

**Quality by Drucker:** According to Drucker (1985) “quality in a product (...) is not what the supplier puts in (...) it is what the customer gets out and is willing to pay for”.

### 3.3 Model quality

The importance of modeling is increasing (see Section 2.2). The goal of this thesis is to provide means for measuring and estimating quality of business process models. Model quality is defined as “the correctness and completeness of software models and their meanings” Unhelkar (2005). The subject of model quality has obtained greater attention already since the year 2004 (Mohagheghi, Dehlen and Neple, 2009). This directly reflects in the need to assure the quality of BPMN models.

Mohagheghi, Dehlen and Neple (2009) performed a systematic search in order to review the literature on the topic of model quality. The focus of this paper is also set on model quality, however considering only business process models created with the use of BPMN. Therefore, the classification of model quality goals developed by Mohagheghi, Dehlen and Neple (2009) is discussed among other literature references in Section 4.

Most research papers that were examined as part of this thesis, discuss the quality of models in *Unified Modeling Language* (UML) (e.g. (Unhelkar, 2005; Arendt and Taentzer, 2010; Mohagheghi, Dehlen & Neple, 2009)). One of the reasons for this may be the popularity of UML because UML is described in many sources with numerous examples of use. In accordance with Mohagheghi, Dehlen and Neple (2009) UML is currently the most widely used modeling language. Additionally, the first UML standard was released already in the mid-1990s (Watson, 2008). When it comes to BPMN it is still rather a new standard, what could be the reason for the minor number of publications about the quality of business processes modelled in BPMN.
3.4 Metamodel of models for assessing the quality of business processes models in BPMN

This section is aimed to answer research question RQ1: “What constitutes the metamodel of models for assessing the quality of business process models in BPMN based on ISO/IEC 1926 standard recommendations on software product quality?”.

3.4.1 Software quality in ISO/IEC 9126 standard

ISO/IEC 9126 (2001) is a standard from the International Organization for Standardization. ISO/IEC 9126 is currently established as one of the most widespread quality standards (Botella et al., 2004).

The standard is intended to help in the software product evaluation. The evaluation process consists of three steps:

- Quality Requirement Definition,
- Evaluation Preparation,
- Evaluation Procedure.

Quality Requirement Definition is a stage in which requirements are specified in terms of quality characteristics and possible subcharacteristics (wider explanation is given below).

Evaluation Preparation is intended to prepare the basis for evaluation. The following actions are a part of the process: quality metrics selection, rating levels definition and assessment criteria definitions (wider explanation is given below).

The process of the Evaluation Procedure is composed of three consecutive sub-processes: measuring, rating and assessing:

- Measurement is defined as “the action of applying a software quality metric to a specific software product”.
- Rating is defined as “the action of mapping the measured value to the appropriate rating level associated with the software for a specific quality characteristic”.
- Assessment is defined as “an action of applying specific documented assessment criteria to a specific software module, package, or product for the purpose of determining acceptance or release of the software module, package or product”.

The ISO/IEC 9126 standard explain that software quality can be described by characteristics. Characteristics should not overlap much. “Software quality characteristics” are defined as “a set of attributes of a software product by which its quality is described and evaluated”. The standard divides the software quality into characteristics: “Functionality”, “Reliability”, “Usability”, “Efficiency”, “Maintainability” and “Portability”. The standard also provides definitions of the characteristics of software quality.
Following (ISO/IEC 9126-1, 2001): “a software quality characteristic may be refined into multiple levels of sub-characteristics”. An Annex A of the ISO/IEC 9126 standard proposes definitions of subcharacteristics of software quality (see Table 3.1).

The ISO/IEC 9126 standard explain that software quality metric allow for direct measurement of quality characteristics. “Software quality metric” is defined in ISO/IEC 9126-1 (2001) as “a quantitative scale and method which can be used to determinate the value a feature takes for a specific software product”.

Finally, ISO/IEC 9126 standard explains that to assess the quality, the results of the evaluation of the different characteristics must be summarized. For this purpose, software quality assessment criteria are used. “Software quality assessment criteria” are defined in ISO/IEC 9126-1 (2001) as “the set of defined and documented rules and conditions which are used to decide whether the total quality of a specific software product is acceptable or not”.

<table>
<thead>
<tr>
<th>Name of characteristics</th>
<th>Name of subcharacteristics</th>
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<tbody>
<tr>
<td>Functionality</td>
<td>Suitability</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
</tr>
<tr>
<td></td>
<td>Interoperability</td>
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<td>Compliance</td>
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<td>Security</td>
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<tr>
<td>Reliability</td>
<td>Maturity</td>
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<td></td>
<td>Fault tolerance</td>
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<td>Usability</td>
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<td>Operability</td>
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<td>Efficiency</td>
<td>Time behaviour</td>
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<td>Conformance</td>
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<td>Replaceability</td>
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Table 3.1. ISO/IEC 9126-1 quality characteristics and sub-characteristics.

Some concepts presented in the standard need to be refined before using standard in a real project (ISO/IEC 1926-1). Among the elements that require to be elaborated before the standard is used in a real project are: subcharacteristics, metrics and method for measurement, rating and assessment. Additionally, the standard say that the importance of the characteristics varies depending on the class of the software and depending on the viewpoints considered. The standard discusses the following views of quality: “user’s view”, “developer’s view” and “manager’s view”.

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3.4.2 The metamodel

In this thesis ISO/IEC 1926-1 standard (see Section 3.4.1) is adopted as a source of the metamodel of models for assessing the quality of business processes models in BPMN (see Figure 3.3). The metamodel is built upon the information presented in the standard.

The aim of the thesis project is to develop and evaluate a model for assessing the quality of business process models in BPMN. The metamodel defines the structure of models for assessing the quality of business process models in BPMN. Therefore, the model developed and evaluated in the thesis (called MAQ) is one of possible instantiations of the metamodel. The metamodel may be used to produce other than MAQ models for assessing the quality of business processes models in BPMN.

All possible models for assessing the quality of business process models in BPMN are in relation to the models modelled in BPMN, as presented on Figure 3.2.

![Figure 3.1. Relation between quality models and BPMN models.](image)

The metamodel (see Figure 3.3) was used throughout the thesis in order to show which instantances of the MAQ model are currently built. Full MAQ model is presented in Section 9. For the evaluation of the MAQ model see Section 10.

![Figure 3.2. Metamodel of models for assessing the quality of business process models in BPMN.](image)

3.4.3 Elements of metamodel

The metamodel (see Figure 3.3) has following main elements of structure: Quality Characteristics, Quality Sub-characteristics, Quality Metrics, Quality Criteria and Quality Functions.
Quality Characteristics

“Software quality characteristics” are defined in ISO/IEC 9126-1 (2001) as “a set of attributes of a software product by which its quality is described and evaluated”. In the metamodel, quality characteristics are defined as “a set of attributes of a BPMN model by which its quality is described and evaluated”.

Following (ISO/IEC 9126-1, 2001): quality characteristics “provide a baseline for further refinement and description of (...) quality”. The characteristic should not overlap much.

Quality Sub-characteristics

Following (ISO/IEC 9126-1, 2001): “a software quality characteristic may be refined into multiple levels of sub-characteristics”.

In the metamodel, quality sub-characteristics should not overlap much and its definition should cover a part of a definition of the related quality characteristic.

Quality Metrics

“Software quality metric” is defined in ISO/IEC 9126-1 (2001) as “a quantitative scale and method which can be used to determine the value a feature takes for a specific software product”. In the metamodel, quality metric is defined as “a quantitative scale and method which can be used to determine the value a feature takes for a specific BPMN model”.

In (ISO/IEC 9126-1, 2001), “For measurement, the selected metrics are applied to the software product. The result is values on the scales of the metrics.”. Similarly, in the metamodel, for measurement, the selected metrics are applied to the BPMN models. The result is values on the scales of the metrics.

Quality Criteria

In (ISO/IEC 9126-1, 2001) and in the metamodel, “in the rating step, the rating level is determinated for a measured value”. The rating level in the metamodel is called Quality Rating.

In the metamodel, quality criteria is used to determinate the rating level associated with the result (obtained value on the scale of the quality metric for a specific BPMN model).

Quality Functions

In (ISO/IEC 9126-1, 2001) “assessment is the final step of the software evaluation process where a set of rated levels are summarized”. Similarly, in the metamodel, assessment is the final step of the BPMN model evaluation process where a set of rated levels are summarized.

Following (ISO/IEC 9126-1, 2001), “to assess the quality of the product, the results of the evaluation of the different characteristics must be summarized”. These are called assessment criteria.
“Software quality assessment criteria” are defined in ISO/IEC 9126-1 (2001) as “the set of defined and documented rules and conditions which are used to decide whether the total quality of a specific software product is acceptable or not”. \textbf{In the metamodel}, this role has \textbf{quality functions}. Taking into account also that ISO/IEC 9126-1 (2001) in Annex suggests to measure subcharacteristics, \textbf{in the metamodel}, \textbf{quality functions} are defined as follows “the defined and documented functions which are used to decide whether the quality of quality sub-characteristic or total quality of a specific BPMN model is acceptable or not”.

The ISO standard suggests that “the evaluator has to prepare a procedure for (assessing quality) using for instance, decision tables or weighted \textbf{averages}”. For assessing the quality \textbf{in the metamodel}, also using \textbf{weighted averages} is suggested.

\textbf{Other elements of the metamodel:}

\textbf{<<data type>> Name}
Name of a quality characteristic or a quality sub-characteristic (String value).

\textbf{<<data type>> Definition}
Natural language definition of a quality characteristic or a quality sub-characteristic (String value).

\textbf{<<data type>> Equation}
Mathematic equation of the quality metric.

\textbf{<<data type>> Trend}
Desired trend of values that are favourable for a specific quality metric. For example, the lower obtained value of the quality metric by a BPMN model, the better quality of the model.

\textbf{<<enumeration>> QualityRating}
Defined rating levels for measured values.

\textbf{Class Scale}
Is used to define mathematical possible scale of results that potential BPMN model may obtain. Additionally the class is used to specify a scale of results obtained by a repository of real BPMN models (this scale is a subset of the possible scale of results).

\textbf{3.4.4 Functions in metamodel}

The metamodel of models for assessing the quality of business process models in BPMN constitutes of five main elements (see \textbf{Section 3.4.4}). These are:

1. quality characteristics,
2. quality sub-characteristics,
3. quality metrics,
4. quality criteria,
5. quality functions,
Mathematically quality metrics, quality criteria and quality functions are functions. The following function signatures can be used to define these elements of the metamodel. The method of calculation of the functions should be specified in a concrete model for assessing the quality of business process models in BPMN.

Quality metrics are functions that through measures provide real values or are undefined for models in BPMN:
\[ QM_i : BPMNmodel \rightarrow \{ \text{Real} \cup \text{‘Undefined’} \}, \quad i \in N, i \leq || \text{Quality Metric} || \]

Quality criteria are functions that examine if the values of metrics are acceptable or not for a certain model in BPMN. For each \( QM_i \) function, \( QC_i \) function is specified.
\[ QC_i : BPMNmodel \rightarrow \text{Quality Rating} \quad i \in N, i \leq || \text{Quality Metric} || \]

Quality functions assess the quality sub-characteristics and overall quality of BPMN model:
\[ QF_k : BPMNmodel \rightarrow \text{Quality Rating} \quad k \in N, k \leq || \text{Quality Sub-characteristic} || \]
\[ QF_{MAQ} : BPMNmodel \rightarrow \text{Quality Rating} \]

3.4.5 Implementation of the model derived from the metamodel

A tool that implements a model for assessing the quality of business process models in BPMN is helpful for an automatic assessment of quality. The tool can be seen as a box that takes as input models in BPMN and returns the assessment of their quality (see Figure 3.1).

![Figure 3.3. Tool that implement the model seen as a box.](image)

A result of this thesis is a model for assessing the quality of business process models in BPMN with defined structure and definition and its implementation (a tool).

3.4.6 Example of a model derived from the metamodel

Figures 3.4-3.9 show an example model that is an instantiation of the metamodel from Figure 3.3. The model is a one possible example of a model for assessing the quality of business process models in BPMN.
Figure 3.4 contains only a first part of the model – instantiations of Quality Model, Quality Characteristics and Quality Subcharacteristics. First Quality Characteristic (Ch1) has two Quality Subcharacteristics: SCH1 and SCH2. Second Quality Characteristic (Ch2) has only one Quality Subcharacteristic: SCH3.

Figure 3.4. First part of the model: Quality Characteristics and Quality Subcharacteristics.

Figure 3.5 is a continuation of the first part of the model from Figure 3.4 and includes two Quality Metrics with Quality Criteria. Quality Metric QM1 is associated to all Quality Subcharacteristics (SCH1, SCH2 and SCH3), while Quality Metric QM2 is only associated to Quality Subcharacteristic SCH3. QM2 is a metric specific only to one Quality Subcharacteristic. On the Figure 3.5 Quality Criteria have specific scales of results.

Figure 3.5. Second part of the model from Figure 3.4: Quality Metrics and Quality Criteria.
**Figure 3.6** is a third part of the model from **Figure 3.4** and includes one Quality Function (QFsub1). QFsub1 is associated to SCH1, QC1 and QC2.

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**Figure 3.6.** Third part of the model from **Figure 3.4**: Quality Function for SCH1.

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**Figure 3.7** is a fourth part of the model from **Figure 3.4** and includes one additional Quality Function (QFsub2). QFsub2 is associated to SCH2, QC1 and QC2.

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**Figure 3.7.** Fourth part of the model from **Figure 3.4**: Quality Function for SCH2.
**Figure 3.4** is a fifth part of the model from **Figure 3.4** and includes last local Quality Function (QFsub3). QFsub3 is associated to SCH3, QC1 and QC2.

**Figure 3.8** shows a full model with a global Quality Function (QFmodel). QFmodel is associated to Model, QFsub1, QFsub2 and QFsub3.

**Figure 3.8**. Fifth part of the model from **Figure 3.4**: Quality Function for SCH3.

**Figure 3.9**. Full model from **Figure 3.4** with global Quality Function.
3.5 Discussion

The model for assessing the quality of business process models in BPMN was only found to be directly related to the findings of one other paper. The contribution of the paper, known as the 3QM-Framework (Overhage, Birkmeier & Schlauderer, 2012), focused on different aspects of quality as well as evaluating measurements which differ from the measurements proposed in this thesis.

The 3QM-Framework provided quality marks, metrics and measurement procedures which mainly focus on evaluating quality characteristics on handwritten BPMN models. Moreover, the 3QM-Framework was evaluated through the consensus of a group of experts. This thesis differs by proposing a model with quality characteristics, quality metrics, quality criteria and quality functions which are traceable to research. Moreover, real BPMN models are evaluated automatically, and the evaluation is validated using a survey of experts. The conclusions of the 3QM-Framework paper do not provide a model which combines the results of the measures as this thesis does, but focuses on defining a set of measures as part of the 3QM-Framework itself.

Gonzalez et al. (2010) presented a systematic review of measurements for business processes. Many of the quality metrics in this thesis were selected based on this systematic review. Similar to the findings of the literature review in this thesis, Gonzalez et al. (2010) also found that most metrics have been adapted from the software engineering.

This Master Thesis is aimed to build and evaluate a model for assessing the quality of business process models in BPMN (MAQ) and the tool that implements the model. However, some of the elements of the MAQ model are not newly proposed but combined from elements that come from the existing literature. First of all, the MAQ builds upon quality characteristics that were extracted through a systematic literature review. Additionally, quality metrics used in the MAQ model were taken from literature based on a literature search and selection criteria. They are not new, only sometimes adjusted to meet the needs of the BPMN notation.

Despite the fact that this paper corresponds to the quality of business process models in BPMN, it is worth to mention that quality is also widely researched in the neighbouring or more general disciplines. For example, it is discussed in software engineering, information and services management and manufacturing (Heravizadeh, Mendling & Rosemann, 2008). The quality of developed models which is the main topic of this paper is only a part of the more complex problem of the quality in model-based software development.

Furthermore, proper measurement of the quality of the developed BPMN models cannot be examined separately from its other aspects. Mohagheghi, Dehlen and Neple (2009) mentioned the importance of quality of modelling languages and modelling tools. Not without significance, is also the knowledge and the experience of people who create BPMN models (Vanderfeesten et al., 2008), especially because business process models are managed by many stakeholders, e.g. business process analysts, domain experts, technical analysts and software developers. However, also other business people cope with issues related to BPMN models because they manage and/or monitor the processes that are modelled (Aguilar et al., 2009).

While speaking about the quality of business process models in BPMN, at least few words should be dedicated to the topic of the quality of business processes.
Following (Heravizadeh, Mendling & Rosemann, 2008), the process quality is “the ability of a process to produce and deliver quality products”. Heravizadeh, Mendling and Rosemann (2008) identified quality categories of business process quality (Function, Input/Output, Non-Human Resource and Human Resource) and warned that the quality dimension of a process is usually taken into consideration not deeply enough or is completely forgotten in business process modelling and design. Another very important aspect of process quality is the ability of process changes and automation. Pant and Juric (2008) listed possible effects of process optimization. These are: increased sales, cost savings, improved efficiency in business operations, increased customer satisfaction and improved exception handling. These are also reasons why it is highly desirable to assess the quality of business processes while modelling.

The aforementioned aspects relate to the “surrounding” of the quality of business process models in BPMN but cannot be treated as having no impact on the quality of BPMN models. However, they will not be taken into further consideration in this paper.

Further related research is extensively described in the relevant sections, Sections 4 and 5. This was chosen by the author of the thesis in order to provide relevant literature near the context in which it was used.
4 QUALITY CHARACTERISTICS AND
SUB-CHARACTERISTICS FOR BUSINESS PROCESS
MODELS – SYSTEMATIC LITERATURE REVIEW

4.1 Introduction

According to Kitchenham and Charters (2007), “a systematic literature review (...) is a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest”. The synthesis of the literature presented in this section, was conducted using a well-defined methodology and search strategy with the specified research questions being addressed.

The systematic literature review method was applied in order to answer two research question of the thesis:

- (RQ2.1): “What quality characteristics of models exist?” results of the systematic literature review for RQ2.1 are presented in Appendix A.
- (RQ2.1.1): “Which of the identified quality characteristics are suitable to the developing model?” results of the systematic literature review for RQ2.1.1 are presented in Section 4.6.1 and the evidence from the literature is presented in Appendix B.

In the literature “quality characteristics” are also called “quality attributes” or “quality goals”. In some papers more general terminology such as “quality classification” or “quality criteria” is used. This paper will adopt the term “quality characteristics” to describe quality aspects of models in BPMN (see Section 3.4). The term “quality characteristics” seems for the author of the thesis to be the most commonly used in this context throughout the research papers. Additionally, the term “quality criteria” will have a different meaning in this paper (see Section 7).

Characteristics describe various aspects of the quality. However they are not detailed enough, therefore general characteristics are broken into sub-characteristics. The resulting sub-characteristics cover smaller aspects of the quality. Some researchers also further decompose sub-characteristics or add to them attributes. Finally, the set of characteristics and sub-characteristics subsequently determined and gathered together constitute a hierarchical structure for assessing the quality.

4.2 Review questions

The review questions to be addressed by this study are:

RQ2.1: “What quality characteristics of models exist?”

RQ2.1.1: “Which of the identified quality characteristics are suitable to the developing model?”
4.3 **Review Methods**

This section describes a review protocol, consisting of several steps as outlined in Kitchenham and Charters (2007).

4.3.1 **Data sources and search strategy**

In order to make the process replicable, the sufficient details of search strategy are documented below. For addressing research questions, the search process must identify relevant studies. Therefore, the search strategy was based on the following steps:

1. Identification of keywords, which are alternate words and synonyms for terms used in the research questions, topic of the thesis and/or its domain (see Section 4.3.4.1.). This was done to minimize the effect of differences in terminologies.
2. Building search queries based on the identified keywords (see Section 4.3.4.2.).
3. Search databases. The used strategy for searching was conducted in two-phases (see Figure 4.1.).

In the first phase, the search was conducted within seven electronic databases: ACM Digital Library, SpringerLink, ScienceDirect, Emerald, Academic Search Complete, Elsevier/ICM and ProQuest. These electronic databases were chosen because they are commonly used for searching literature in the field of the Software Engineering. Some of the search queries were applied for searching in all fields, the rest was applied to search within titles, abstracts and keywords. Next, after eliminating duplicates found by more than one electronic database, the author of the thesis read titles and abstracts in all of the found papers and chose literature for further reading based on the inclusion and exclusion criteria. Finally, the author of the thesis read the full text of the filtered literature and selected literature relevant for the topic of this systematic literature review. To results of the first phase of searching, the author of the thesis included one study, which was relevant to the topic (for explanation see Section 4.3.4.3.). These studies were then used later in the second phase of searching.

After the first phase of searching, the author of the thesis initiated a second phase in order to obtain a more representative set of studies. In this phase, the author of the thesis scanned the reference lists of all the selected literature in order to identify further papers. Next, if the literature was claimed to be relevant, it was found in the electronic databases. The author of the thesis reviewed the titles and abstracts of the identified papers. Based on the inclusion and exclusion criteria and full text exclusion, additional literature relevant for the topic was added to the results of the systematic literature review.
4.3.2 Study selection

During the search process, the literature was included or excluded based on the studies selection criteria. The goal was to find literature that provided evidence directly related to the research questions.

4.3.2.1 Inclusion criteria

1. Study describes quality characteristics and/or sub-characteristics of models.
2. Study is written in English, Polish or German.
3. Study must contain the search keywords.
4. Full study can be accessed through one of the online libraries: ACM Digital Library, SpringerLink, ScienceDirect, Emerald, Academic Search Complete, Elsevier/ICM or ProQuest.
4.3.2.2 Exclusion criteria

1. Study describes quality characteristics and/or sub-characteristics of software products.
2. Study does not relate to Software Engineering/Development.

4.3.3 Study quality assessment

The selection of the final articles was done by applying the quality criteria. The author of the thesis did not assign any priorities to the criterion but used a binary “yes”/”no” scale. In order for literature to be selected it needed to provide “yes” answer for all the questions in the checklist. The quality assessment checklist that helped to identify the relevant articles to this study was as follows:

1. Is the reader able to understand the aims of the study?
2. Is the context of study clearly stated to include: type of models (e.g. UML models, conceptual models, etc.) and the purpose of modelling, even general (e.g. modelling systems in order to tackle complexity by providing abstractions and hiding superfluous technical details)?
3. Is the study useful for extraction of characteristics for business process models in BPMN?
4. Does the study have a clear and coherent description of the quality characteristics and/or sub-characteristics of process models?
5. Is the rationale and/or limitations of the study discussed?

4.3.4 Data extraction

4.3.4.1 Keywords

The following are the keywords that were formulated from the research questions, synonyms and meaningful combination of them. Nevertheless, only underlined keywords were used to build search queries (Section 4.3.4.2) in order to find relevant articles.

- BPMN
- business process models
- model-based software development
- model-driven engineering
- conceptual modelling
- quality
- model quality
- quality characteristics
- quality attributes
- quality properties
- quality goals
- quality classification
- quality criteria
- quality of business process models
- quality framework
- model quality goals
4.3.4.2 Search queries

Pilot searches showed that the above listed keywords were very general and when searching using them the results were too broad. Therefore, in order to search databases and obtain relevant results, the author of the thesis used some of the identified keywords and built queries based on the Boolean AND to join major terms. Furthermore, the author of the thesis did not limit the year of publication in any of the search queries in order to be more inclusive:

1) “model quality” AND “business process models” (in all fields)
2) “quality characteristics” AND “business process models” AND BPMN (in all fields)
3) “quality goals” AND “business process models” AND BPMN (in all fields)
4) “quality of business process models” (in all fields)
5) “conceptual modeling” (in all fields) AND “model quality” (in title)
6) “model-driven engineering” (in all fields) AND quality (in title)

4.3.4.3 Search results

The results of the first phase of the search are enclosed in Tables 4.1-4.6. The columns labelled “Literature chosen for further reading” in Tables 4.1-4.6 contain literature chosen for full text reading. In order to eliminate duplicates that were found in more than one electronic database, the original paper was left in the row of the database in which the literature was found first and was not repeated in next tables.

Results of papers selected for the full text reading during second phase of the search are enclosed in Table 4.7. A summary of the results of the search is enclosed in Table 4.8.

1) “model quality” AND “business process models” (in all fields)

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of results</th>
<th>Literature chosen for full text reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>8</td>
<td>None</td>
</tr>
<tr>
<td>SpringerLink</td>
<td>154</td>
<td>(Nelson et al., 2012)</td>
</tr>
<tr>
<td>ScienceDirect</td>
<td>26</td>
<td>None</td>
</tr>
<tr>
<td>Emerald</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Elsevier/ICM</td>
<td>21</td>
<td>(Mohagheghi, Dehlen &amp; Neple, 2009)</td>
</tr>
<tr>
<td>Academic Search Complete</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>ProQuest</td>
<td>25</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 4.1. Distribution of papers for query number 1 (first phase of the search).

2) “quality characteristics” AND “business process models” AND BPMN (in all fields)

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of results</th>
<th>Literature chosen for full text reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>SpringerLink</td>
<td>31</td>
<td>None</td>
</tr>
<tr>
<td>ScienceDirect</td>
<td>6</td>
<td>(Mendling, Reijers &amp; van der Aalst, 2010)</td>
</tr>
<tr>
<td>Emerald</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>Academic Search Complete</td>
<td>48</td>
<td>None</td>
</tr>
<tr>
<td>Elsevier/ICM</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>ProQuest</td>
<td>3</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 4.2. Distribution of papers for query number 2 (first phase of the search).
3) “quality goals” AND “business process models” AND BPMN (in all fields)

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of results</th>
<th>Literature chosen for full text reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>SpringerLink</td>
<td>16</td>
<td>(Overhage, Birkmeier, Schlauderer, 2012)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Reijers, Mendling &amp; Recker, 2010)</td>
</tr>
<tr>
<td>ScienceDirect</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Emerald</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Elsevier/ICM</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Academic Search Complete</td>
<td>48</td>
<td>None</td>
</tr>
<tr>
<td>ProQuest</td>
<td>1</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 4.3. Distribution of papers for query number 3 (first phase of the search).

4) “quality of business process models” (in all fields)

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of results</th>
<th>Literature chosen for full text reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>SpringerLink</td>
<td>31</td>
<td>(Becker, Rosemann &amp; von Uthmann, 2000)</td>
</tr>
<tr>
<td>ScienceDirect</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>Emerald</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>Elsevier/ICM</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td>Academic Search Complete</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td>ProQuest</td>
<td>4</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 4.4. Distribution of papers for query number 4 (first phase of the search).

5) “conceptual modelling” (in all fields) AND “model quality” (in title)

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of results</th>
<th>Literature chosen for full text reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>SpringerLink</td>
<td>8</td>
<td>(Cherfi, Akoka &amp; Comyn-Wattiau, 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ssebuggwawo, Hoppenbrouwers &amp; Proper, 2010)</td>
</tr>
<tr>
<td>ScienceDirect</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Emerald</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Elsevier/ICM</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>Academic Search Complete</td>
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<td>None</td>
</tr>
<tr>
<td>ProQuest</td>
<td>1</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 4.5. Distribution of papers for query number 5 (first phase of the search).

6) “model-driven engineering” (in all fields) AND quality (in title)

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of results</th>
<th>Literature chosen for full text reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>156</td>
<td>None</td>
</tr>
<tr>
<td>SpringerLink</td>
<td>32</td>
<td>(Jalbani et al., 2009)</td>
</tr>
<tr>
<td>ScienceDirect</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Emerald</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Elsevier/ICM</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>Academic Search Complete</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>ProQuest</td>
<td>10</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 4.6. Distribution of papers for query number 6 (first phase of the search).
List of selected papers from the first phase of the search:
1. (Becker, Rosemann & von Uthmann 2000)
2. (Nelson et al., 2012)
3. (Mohagheghi, Dehlen & Neple, 2009)
4. (Mendling, Reijers & van der Aalst, 2010)
5. (Overhage, Birkmeier, Schlauderer, 2012)
6. (Reijers, Mendling & Recker, 2010)
7. (Cherfi, Akoka & Comyn-Wattiau, 2003)
8. (Ssebuggawo, Hoppenbrouwers & Proper, 2010)
9. (Jalbani et al., 2009)
10. (Arendt & Taentzer, 2010) – added by the author of the thesis to the results of the search

The reason why (Arendt & Taentzer, 2010) paper was included to the list of selected papers from the first phase of the search is because the paper touches the problem of model quality in one section, which serve as a basis for assignments of model smells and model refactorings, what is the major concern of the paper. In the section of model quality the paper cites German paper by Fieber, Huhn and Rumpe (2008), which contain a taxonomy of model quality aspects. The taxonomy is given in Section 4.4.8 and the description is based on original source, that is (Fieber, Huhn & Rumpe, 2008).

Table 4.7. Papers selected after the full text reading at the second phase of the search.

<table>
<thead>
<tr>
<th>Selected papers from the first search phase:</th>
<th>Literature chosen after full text reading obtained through scanning references of the selected papers (only literature that was available from databases):</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Becker, Rosemann &amp; von Uthmann 2000)</td>
<td>(Lindland, Sindre &amp; Sølvberg, 1994)</td>
</tr>
<tr>
<td>(Nelson et al., 2012)</td>
<td>None</td>
</tr>
<tr>
<td>(Mohagheghi, Dehlen &amp; Neple, 2009)</td>
<td>(Unhelkar, 2005)</td>
</tr>
<tr>
<td></td>
<td>(Krogstie &amp; Sølvberg, 2000)</td>
</tr>
<tr>
<td>(Mendling, Reijers &amp; van der Aalst, 2010)</td>
<td>None</td>
</tr>
<tr>
<td>(Overhage, Birkmeier, Schlauderer, 2012)</td>
<td>None</td>
</tr>
<tr>
<td>(Reijers, Mendling &amp; Recker, 2010)</td>
<td>None</td>
</tr>
<tr>
<td>(Ssebuggawo, Hoppenbrouwers &amp; Proper, 2010)</td>
<td>None</td>
</tr>
<tr>
<td>(Jalbani et al., 2009)</td>
<td>(Lange &amp; Chaudron, 2005)</td>
</tr>
<tr>
<td></td>
<td>(Mohagheghi &amp; Aagedal, 2007)</td>
</tr>
<tr>
<td>(Arendt and Taentzer, 2010)</td>
<td>(Fieber, Huhn &amp; Rumpe, 2008)</td>
</tr>
</tbody>
</table>

List of selected papers from the second phase of the search:
1. (Lindland, Sindre & Sølvberg, 1994)
2. (Unhelkar, 2005)
3. (Krogstie & Sølvberg, 2000)
4. (Reinhard & Rotthowe, 1998)
5. (Mohagheghi & Aagedal, 2007)
6. (Lange & Chaudron, 2005)
7. (Fieber, Huhn & Rumpe, 2008)
Final list of selected papers contains papers from both the first and the second phase of the search.

<table>
<thead>
<tr>
<th>Phase of searching:</th>
<th>First phase</th>
<th>Second phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of the literature found (with multiple duplicates, in all electronic databases):</td>
<td>657</td>
<td>–</td>
</tr>
<tr>
<td>Number of the literature chosen for further reading basing on the titles and abstracts and inclusion and exclusion criteria:</td>
<td>9 + 1</td>
<td>11</td>
</tr>
<tr>
<td>Number of the literature relevant for the topic of this systematic literature review:</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 4.8. Summary of the search results.

4.4 Results and synthesis of findings

As a result of the systematic literature review, some quality characteristics of models were found in the literature (RQ2.1). This section will summarise the findings.

4.4.1 Quality framework by Lindland, Sindre and Sølvberg (1994)

A Quality framework for model quality consisting of the following elements (Lindland, Sindre & Sølvberg, 1994):

- **Syntax quality** – adhering to the rules in the language,
- **Semantic quality** – correct meaning and relations,
- **Pragmatic quality** – comprehensibility for the intended users.

4.4.2 Quality framework by Krogstie and Sølvberg (2000)

Krogstie and Sølvberg (2000) added two classifiers to the quality framework from previous studies described in (Lindland, Sindre & Sølvberg, 1994). The revised framework for model quality consists of the following elements (Krogstie & Sølvberg, 2000):

- **Syntax quality** – adhering to the rules in the language,
- **Semantic quality** – correct meaning and relations,
- **Pragmatic quality** – comprehensibility for the intended users,
- **Organizational quality** – whether a model fulfils the goals of modelling and that all the goals of modelling are addressed through the model,
- **Technical pragmatic quality** – being interpretable by tools.

4.4.3 6C goals by Mohagheghi, Dehlen and Neple (2009)

6C goals (six model quality goals) is a classification proposed by Mohagheghi, Dehlen and Neple (2009) based on their review of the literature and their previous work on developing a quality model for MDE (Model-Driven Engineering). This classification is meant to be more accurate for the concepts used in modelling:
6C goals include (Mohagheghi, Dehlen & Neple, 2009):

- **C1-Correctness** – Definition:
  a. “including right elements and correct relations between them, and including correct statements about the domain” and
  b. “not violating rules and conventions; for example adhering to language syntax, style rules, naming guidelines or other rules or conventions”.

- **C2-Completeness** – Definition: “having all the necessary information that is relevant and being detailed enough according to the purpose of modelling”.

- **C3-Consistency** – Definition: “no contradictions in the model”. Consistency also covers semantic consistency between models. For example, one element cannot have multiple meanings in different diagrams or models.

- **C4-Comprehensibility** – Definition: “being understandable by the intended users; either human users or tools.”

- **C5-Confinement** – Definition: “being in agreement with the purpose of modeling and the type of system”. For example relevant diagrams are included and they are at the right level of abstraction. A model that is confined includes only necessary information and is complex and detailed only as much as is needed.

- **C6-Changeability** – Definition: “supporting changes or improvements so that models can be changed or evolved rapidly and continuously”.


Following Cherfi, Akoka and Comyn-Wattiau (2003), it is possible to measure the quality of a model by its capabilities and it can be described by three non-orthogonal dimensions:

1) **Specification dimension** (aimed to obtain a formal representation of the observed reality)
   - **Legibility** (ease in reading the model)
     - **Clarity** (aesthetic criterion)
     - **Minimality** (if aspects of the requirements appear multiple times)
   - **Expressiveness** (representative of user requirements)
     - **Concept expressiveness** (if concepts are expressive enough, that is, if they capture the main aspects of reality)
     - **Schema expressiveness** (if the whole model is expressive)
   - **Simplicity** (if the model contains the minimum possible constructs)
   - **Correctness**
     - **Syntactic correctness** (if concepts are properly defined in the model)
     - **Semantic correctness** (if concepts are used according to their definitions)

2) **Usage dimension** (aimed to meet requirements of users)
   - **Completeness** (if the model represents all relevant features of the domain)
   - **Understandability** (if the user can easily interpret the model)

3) **Implementation dimension** (aimed to facilitate a basis for future implementation of the system)
   - **Implementability** (amount of effort needed to implement the conceptual model)
   - **Maintainability** (if the conceptual model can easily evolve)
4.4.5 The Perceived Quality of the End Products (PQEP) by Ssebuggwawo, Hoppenbrouwers and Proper (2010)

In (Ssebuggwawo, Hoppenbrouwers & Proper, 2010), quality dimensions for end-products (models) are proposed, along with two other dimensions: modelling language and modeling procedure. The quality dimensions for PQEP constructs contain:

- **Product Quality** – adequate representation of the domain concepts in the model,
- **Understandability** – syntax, semantics of the model,
- **Modifiability and Maintainability** – ease of changing the model,
- **Satisfaction** – modeller’s positive feelings about the quality of the model.

4.4.6 A Conceptual Modeling Quality Framework (CMQF) by Nelson *et al.* (2012)

The quality framework by Nelson *et al.* (2012) was built upon the strengths of two other frameworks, among which there is the aforementioned (Section 5.6.) framework proposed by Lindland, Sindre and Sølvberg (1994). It focuses on the product of conceptual modeling: models. The other framework focuses on the process of conceptual modeling therefore is not relevant in this paper. In the CMQF framework, quality types are assigned to layers which follow the conceptual modeling process. Below, the types which are underlined, are relevant to the main topic of the thesis, i.e., they do not assess the modeling language or the stakeholders’ knowledge of the domain. This is the focus of the rest of the quality types. The layers and quality types in CMQF are as follows:

1) **Physical layer:**
   - **Model-Domain Appropriateness** (model must be appropriate to the domain being modelled),
   - Ontological Quality,
   - **Syntactic Quality** (all elements of the model must be able to be derived from the vocabulary and the grammar of the language),
   - **Semantic Quality** (model must accurately and completely capture the meaning of the domain),
   - Language-Domain Appropriateness,
   - **Intentional Quality** (meanings defined by the model must remain true in its physical representation),
   - **Empirical Quality** (readability of the model).

2) **Knowledge layer** – Quality types in knowledge layer parallel to the quality types in the physical layer, although in the knowledge layer they exist only cognitively in the minds of stakeholders.

3) **Learning layer:**
   - View Quality,
   - Pedagogical Quality,
   - Linguistic Quality,
   - Pragmatic Quality.

4) **Development layer:**
   - **Applied Domain-Model Appropriateness** (physical model being developed must be appropriate to the understanding of the domain by a modeller),
   - Applied Domain-Language Appropriateness,
   - Applied Domain Knowledge Quality.
– Applied Model-Language Appropriateness,
– Applied Model Knowledge Quality,
– Applied Language Knowledge Quality.

4.4.7 SIQ framework for process models by Mendling, Reijers and van der Aalst (2010)

In (Mendling, Reijers & van der Aalst, 2010), some existing techniques and approaches to the topic of quality of models are gathered, combined and extended. For example, in the paper the same categories of process model quality are distinguished as in a previous model. They originally come from (Lindland, Sindre & Solvberg, 1994), however in the SIQ framework two sub-categories of semantic quality are added:

– **Syntactic quality** – the model's statements should be according to the syntax and vocabulary of the modeling language.

– **Semantic quality** – the model's statements should be true in relation to the real world. It captures as is processes and to be processes.
  - **Validity** – all model's statements are correct and relevant to the problem.
  - **Completeness** – all model's statements would be correct.

– **Pragmatic quality** – relates to the understandability of the model by people.

4.4.8 A taxonomy of model quality aspects by Arendt and Taentzer (2010)

A taxonomy of model quality was proposed by Fieber, Huhn and Rumpe (2008). The taxonomy was discussed also by Arendt and Taentzer (2010).

The taxonomy includes (Fieber, Huhn and Rumpe, 2008):

– **Presentation (deu. Darstellung)** – this characteristic refers to the visual perception and its acceptance by the user. For instance, it relates to the assessment how good the layout of a diagram is or whether there are many elements displayed in it.

– **Simplicity (deu. Einfachheit)** – this characteristic relates to the complexity of the model. It refers to problems such as too complex models or how complex aspect is modelled.

– **Conformity (deu. Konformität)** – this characteristic relates to the conventions and conformance with modelling standards. It covers the situation of their respect or violation, e.g. abidance of the naming conventions.

– **Cohesion/Modular design (deu. Kohäsion/Modularisierung)** – these characteristics are strongly related to the coupling of model elements. Cohesion is related to dependent system aspects and the modular design is related to technical independent aspects or independent aspects with regards to content.

– **Redundancy (deu. Redundanz)** – this characteristic refers to the fact if redundancy is mandatory in the model.

– **Semantic adequacy (deu. Semantische Adäquatheit)** – this characteristic relates to the use of a proper modelling language, suitable kind of diagram, adequate elements for modelling a specific aspect, etc.

– **Correctness (deu. Korrektheit)** – this characteristic refers to semantic and syntactic correctness of the model.

– **Precision (deu. Präzision)** – this characteristic is concerned with the description of only relevant features of the domain or other artefacts
in the models. In a precise model each omitted feature of the original aspect is in fact irrelevant for the current development phase or modelling purpose.

- **Completeness wrt. proceeding phases (deu. Vollständigkeit nach oben)** – these characteristics show if all requirements are completely covered by the model and if all information from the preceding phase in the model chain is completely transferred to the correct phase.

- **Completeness wrt. subsequent phases (deu. Vollständigkeit nach unten)** – these characteristics relate to models of one level in the model chain. They tell whether the model contain all necessary information to deduce or generate the artefacts of the subsequent phase.

- **Traceability (deu. Verfolgbarkeit)** – this characteristic expects the relationship between models across multiple stages. For instance, by using traceability statements, the completeness wrt. preceding phases can be determined.

- **Changeability (deu. Änderbarkeit)** – this characteristic can further be sub-divided into the aspects maintainability, extensibility, and reusability.

In general, it relates to the ease of making necessary changes to the models.

### 4.4.9 Quality marks from 3QM-Framework by Overhage, Birkmeier and Schlauderer (2012)

Overhage, Birkmeier and Schlauderer (2012) proposed the 3QM-Framework, which among others was built on ISO standard for the quality of software artifacts (ISO/IEC 9126-1, 2001).

The 3QM-Framework is aimed to determine the quality of process models. Additionally, its practical relevance was shown through the results of empirical evaluation in case studies.

The 3QM-Framework contains marks and simple metrics with procedures. To the group of marks belong:

- **Syntactics** – adhesion of the model to the formal rules of modeling language
  - **Text syntax**
  - **Sentence-level syntax**
  - **Word syntax**

- **Semantics** – relevance of the elements of the model to the real world objects
  - **Completeness**
  - **Flexibility**
  - **Correctness**
  - **Relevance**

- **Pragmatics** – interpretation of the model based on the model's presentation
  - **Unambiguity**
  - **Understandability**

### 4.4.10 A set of seven process modeling guidelines (7PMG) by Mendling, Reijers and van der Aalst (2010)

In (Mendling, Reijers & van der Aalst, 2010), a set of seven process modeling guidelines is proposed:

- **G1** – Use as few elements in the model as possible,
- **G2** – Minimize the routing paths per element,
- **G3** – Use one start and one end,
- **G4** – Model as structured as possible,
- **G5** – Avoid OR routing elements,
- **G6** – Use verb-object activity labels,
- **G7** – Decompose a model with more than 50 elements.

The guidelines are based on the analysis of the model structure, error probability and understanding. For those aspects guidelines are intended to improve the quality of business process models.


The goal of Guidelines of Modeling (GoM) framework is to improve the quality of models. In accordance with the framework, the model quality contains six principles (Becker, Rosemann & von Uthmann, 2000):

1) Necessary preconditions for the quality of models:
   - **Guideline of correctness** – syntactic correctness, semantic correctness.
   - **Guideline of relevance** – if elements of the model can be eliminated without loss of meaning for the model user it means that the model includes elements without relevance.
   - **Guideline of economic efficiency**

2) Optional:
   - **Guideline of clarity** – model needs to be readable, understandable and useful.
   - **Guideline of comparability** – in a project it is expected that all guidelines are used consistently.
   - **Guideline of systematic design** – relationships between models, which belong to different views should be well-defined.

### 4.4.12 Quality aspects by Unhelkar (2005)

Unhelkar (2005) listed the following **levels of quality for UML-based projects:** data quality, code quality, model quality, architecture quality, process quality, management quality and quality environment. Additionally, Unhelkar proposed the mapping of the quality of models to: syntax, semantics and aesthetics.

### 4.4.13 Guidelines of Modeling (GoM) by Reinhard and Rotthowe (1998)

Guidelines of Modeling (GoM) by Reinhard and Rotthowe (1998) include principles to ameliorate the quality of information modeling. The following principles relevant to the topic of the thesis are underlined and described.

- **The Principle of Construction Adequacy** – reality adequacy of a model according to the represented problem.
- **The Principle of Language Adequacy** – interrelation between the model and the used language (completeness and consistency of the model).
- The Principle of Economic Efficiency
- **The Principle of Clarity** – comprehensibility and explicitness of the model.
- The Principle of Systematic Design
The Principle of Comparability – comparison of two models regarding their correspondence and similarity.

4.4.14 Lange-Chaudron Quality Model by Lange and Chaudron (2005)

For the purpose of this thesis only quality factors from Lange-Chaudron Quality Model (Lange & Chaudron, 2005) are relevant. Additionally, only quality factors which are relevant to models are mentioned below (quality factors only for system are omitted). The quality factors are also discussed in (Jalbani et al., 2009) and (Mohagheghi & Aagedal, 2007).

The quality factors are as follows:

- **Complexity** – measures the effort needed to understand the model.
- **Balance** – equal degree of description for all parts of the system in all other model characteristics.
- **Correspondence** – system elements, their relations and design decisions are the same in the model and the system.
- **Self-Descriptiveness** – readers have enough information to determine the model's objectives, assumptions, constraints, inputs, outputs, components and status.
- **Esthetics** – model's graphical layout enables ease of understanding.
- **Detailedness** – model describes relevant details of the system.
- **Consistency** – no conflicting information is contained in the model.
- **Traceability** – relations between design decisions in a model are explicitly described.
- **Completeness** – overlapping parts of different model's views contain the same elements and model describes system completely.

4.5 Systematization of quality characteristics for models in BPMN

This section is aimed to summarize the literature findings with respect to obtaining the answer for the RQ2.1.1: “Which of the identified quality characteristics are suitable to the developing model?” . The quality characteristics and quality sub-characteristics presented as a result of the section (see Figure 4.4 and Figure 4.5) are instances of Quality Characteristics and Quality Sub-characteristics from metamodel described in Section 3.4 (see Figure 4.2). Additionally, the MAQ model itself is an instance of the Quality Model. Quality Model has one or more Quality Characteristic and each Quality Characteristic have one or more Quality Sub-characteristics. Grey classes are not presented in this section.
To begin with, Table 4.9 focuses on the exact types of models for which quality characteristics were identified in the chosen literature. The table also contain some theoretical frameworks and guidelines available in the area.

<table>
<thead>
<tr>
<th>ID</th>
<th>Primary studies:</th>
<th>Identified quality characteristics are intended to describe:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>(Krogstie &amp; Solvberg, 2000)</td>
<td>Conceptual models.</td>
</tr>
<tr>
<td>3</td>
<td>(Mohagheghi, Dehlen &amp; Neple, 2009)</td>
<td>Models for Model-Driven Engineering (MDE); especially including Unified Modeling Language models.</td>
</tr>
<tr>
<td>5</td>
<td>(Ssebuggawo, Hoppenbrouwers &amp; Proper, 2010)</td>
<td>Collaborative modeling including end-products (models), modeling languages and modeling procedures.</td>
</tr>
<tr>
<td>6</td>
<td>(Nelson et al., 2012)</td>
<td>Product of conceptual modeling (models) and the process of conceptual modeling.</td>
</tr>
<tr>
<td>7</td>
<td>(Mendling, Reijers &amp; van der Aalst, 2010)</td>
<td>Business process models (aspects of model structure, error probability and understanding)</td>
</tr>
<tr>
<td>10</td>
<td>(Overhage, Birkmeier, Schlauderer, 2012)</td>
<td>Appropriateness of business process models as means of communication (i.e. automation potential, maintainability and modifiability of models not taken into account).</td>
</tr>
<tr>
<td>11</td>
<td>(Reijers, Mendling &amp; Recker, 2010)</td>
<td>Process models (general perspective on the models).</td>
</tr>
</tbody>
</table>
The obtained results concentrate mostly around characteristics of the Unified Modeling Language models – consisting of 8 papers. This is not a surprise, because UML is currently the most widely used modelling language (Mohagheghi, Dehlen & Neple, 2009). The other resulting papers refer to characteristics for: conceptual models (3 papers), collaborative modeling including models (1 paper) and information models (2 papers).

Finally, only 3 papers were found which refer to (business) process models. Of these papers, one corresponds only to the aspects of model structure, error probability and understanding. And in the framework proposed in one additional paper (Overhage, Birkmeier, Schlauderer, 2012) the authors planned to extend it with quality profiles in order to better and more widely meet the requirements for the quality of models.

All in all, the studies, which refer to (business) process models, are new. The papers are from the years between 2010-2012 (Figure 4.3). This shows that the business process modelling domain is coming into focus currently and may be rapidly developing.

Figure 4.3. Resulting papers on models versus years of publications.

Quality assessment of business process models in BPMN has multiple criteria. In the previous section, the quality characteristics of models found in the literature, were gathered and shortly discussed. Some of the characteristics were repeated in several classifications, e.g. semantic and syntactic quality. While others were proposed only in one research paper, e.g. redundancy or organizational quality. Some
of the definitions are vague or unstructured and some proposed properties overlap. Even papers focused on business process models are independent from each other, therefore the proposed quality characteristics differ.

Business process models in BPMN meet the needed quality, if all elements are properly used in an appropriate way. In the following sections, quality characteristics which cannot be measured automatically without having the necessary knowledge of the domain (i.e. expert domain knowledge), or other additional information beyond the model itself will not be taken into further consideration. This may be considered as a limitation of the thesis. Nevertheless, this characteristics cannot be estimated automatically with the use of the tool without any additional information about the domain, but the BPMN model itself. At the same time they are important to be provided, and cannot be neglected in the MAQ model. These characteristics and sub-characteristics are presented on following drawings with dotted borders (see Figure 4.4 and Figure 4.5).

4.5.1 Definitions of quality characteristics of business process models in BPMN

Figure 4.4. presents the chosen quality characteristics in a graphical way. The choice was based on the literature presented in this section. Full evidence and mapping to characteristics for BPMN is presented in Appendix B.

Below, definitions of the quality characteristics which will be used in this thesis are provided. The definitions are the synthesis and/or extensions of the definitions chosen in the previous section. Moreover, the model for assessing the quality of business processes models in BPMN builds upon the hierarchical structure of characteristics and sub-characteristics proposed in the ISO standard (ISO/IEC 9126-1, 2001), which is described in Section 3.

Definitions of the quality characteristics for business process models in BPMN:

- **Correctness** – in accordance with analysis in regards to making correct statements about the domain AND following BPMN notation according to the specification, i.e. not violating rules and conventions (well-formedness and syntactic correctness).
- **Integrity** – description of all and only relevant elements of the domain, business process and purpose of modelling.
- **Modifiability** – ability of the BPMN model to be modified or changed AND supporting reusability and extensibility.
- **Complexity** – related to the complexity of the BPMN model with the goal of simplicity and minimalism.
- **Understandability** – satisfaction of the users and their comprehensibility AND a minimalistic and simplistic BPMN model.
4.5.2 Definitions of quality sub-characteristics of business process models in BPMN

Due to the fact that the list of the characteristics shown in Figure 4.4. is general, sub-characteristics are proposed (see Figure 4.5). The role of the sub-characteristics is to break down the generality of the characteristics and to specify them more concretely in the context of business process modelling.

Sub-characteristics for Correctness:
- **Syntactic correctness** – model in BPMN is syntactically correct if all terms are used in accordance with the syntax rules of the BPMN notation.
- **Semantic correctness** – model in BPMN is semantically correct if it corresponds to the domain and the reality of the analysed situation.

Sub-characteristics for Integrity:
- **Informational completeness** – correct scope of the BPMN model (does model in BPMN include all and only relevant features of the domain).
- **Consistency** – no contradictions in the model and the domain concepts are adequately represented in the model.
- **Accordance with purpose** – is when the BPMN model meets the original goals for why it was created.

Sub-characteristics for Modifiability:
- **Changeability** – support for changes or improvements.
- **Reusability and extensibility** – Support for the model to be used in the creation of new models or extended with new terms.

Sub-characteristic for Complexity:
- **Minimality and simplicity** – if the BPMN model contains the minimum possible constructs.
Sub-characteristics for **Understandability**:

- **User comprehensibility** – being understandable by users — both human users, and tools.
- **Aesthetics of model** – when the organization of the BPMN model is pleasing and improving the look in order to ease its understanding.

![Figure 4.5. Systematized quality characteristics with sub-characteristics for BPMN.](image)

### 4.6 Conclusion

Many of the proposed characteristics and/or sub-characteristics seem to be impossible or unrealistic to be completely satisfied, e.g. completeness can be achieved only up to a certain point. This is because, it is not possible to directly decide whether a model in BPMN is or is not complete by using reality as the reference point. Completeness can only be fully assessed by looking at the BPMN model with additional knowledge. In order to solve this problem, it is necessary to reference external sources of information (e.g. domain experts) in order to assess the completeness of the BPMN model. Similarly, modifiability cannot be always uniquely defined because some business processes may evolve over time. Nevertheless, in each case, if possible, in the next section measures that support the credibility of the characteristics or their lack thereof will be proposed.
To summarize, the systematic literature review (SLR) resulted in the selection of a total of 17 papers that discuss characteristics of models. Additionally, based on the findings from the literature, a systematic understanding of quality characteristics of models in BPMN was proposed. The main contribution in this section was to systematize and/or extend quality characteristics from the literature and refine the area of quality in order to be relevant for business process models in BPMN.

In the following Section 5, quality metrics for some quality characteristics will be discussed, that is, only characteristics that can be measured without knowledge of the domain that is modelled.
5 QUALITY METRICS

5.1 Introduction

Having outlined the quality characteristics for business processes in BPMN (Section 4), important question arise such as how to measure the characteristics and how to interpret the measured values. Even though BPMN is not very new, measuring business process models is a newly emerged discipline (Cardoso, Vanderfeesten & Reijers, 2010).

In order to evaluate the quality of characteristics, a set of quality metrics is required. Metrics can help not only to analyse the quality but also, for example, to suggest better design solutions or to quickly identify error prone processes and redesign them if possible.

The focus of this section is to obtain quality metric(s) for each of the quality sub-characteristics and the knowledge how to calculate each metric and when its values are good. These will provide an answer to RQ2.2: “Which metrics are suitable for the constructed model?”. As a result, a literature review will be conducted.

Researchers often use terms ‘a measure’ and ‘a metric’ interchangeably.

According to ISO/IEC/IEEE 24765 (2010), a measure is defined as “the number or category assigned to an attribute of an entity by making a measurement”.

According to ISO/IEC/IEEE 24765 (2010) a quality metric is “a quantitative measure of the degree to which an item possesses a given quality attribute”.

In this paper, the term ‘metric’ will be used to describe a function that can be applied to calculate certain parameters. However, if the author of the metric used term ‘measure’ in the name of the metric – it has also been presented in this paper.

5.2 Selection criteria for the literature

For each quality characteristic of business process models in BPMN, a metric or a set of metrics was chosen from the literature and rationalized. The choice was based on the selection criteria listed below. The selection criteria are questions that every relevant literature describing metric must affirmatively answer with the exception of question 7. Question 7 is desired, but not mandatory. If no suitable metrics were found in the literature for a specific quality sub-characteristic, the author of the thesis would propose a new metric and validate its usefulness through the survey. If the chosen metrics needed to be changed or adjusted for the sake of better results, the author of the thesis would make all needed changes or adjustments and provide rationale for them.
Selection criteria for **RQ2.2:**

1. Is the metric useful (or can the metric be useful after needed changes or adjustments) for the context of modelling of business processes in BPMN?
2. Is it possible to calculate the metric for business process models in BPMN (directly or after needed changes and/or adjustments)?
3. Is the method of calculating the metric well described in the literature (or is it possible to propose the method of calculating the metric logically)?
4. Is it known from the literature what kind of values obtained as a result of the metric are desired for models (at a minimum: is there a general trend that identifies a good or bad value)?
5. Do not the metrics limitations exclude it from being applicable to the relevant sub-characteristic(s)?
6. Is there support for the usefulness of the metric (or the original metric from which the metric came from) in at least two research papers?
7. Is validation of the metric provided (e.g. was the metric theoretically or empirically validated)?

### 5.3 Quality metrics in literature

This section gathers different measures defined either for BPMN models or for neighbouring and more general disciplines. The author of the thesis chose 17 **metrics** (summary of metrics can be found in **Section 5.7**). Later, the metrics will be assigned to quality sub-characteristics.

The **Quality Metrics** presented in this section are instances of **Quality Metrics** from metamodel described in **Section 3.4** (see **Figure 5.1**). One metric can be assigned to more than one quality sub-characteristic and for each quality sub-characteristic one or more metrics are assigned. In the diagram, grey classes are not presented in this section.

![Diagram](image)

**Figure 5.1.** Resulting elements of the MAQ model are based on the introduced metamodel (see also **Figure 3.2**).
Only a few of the chosen metrics were created specifically for BPMN models. Therefore, the revision or adaption of metrics that seemed to be useful in the BPMN context was conducted. Additional help in choosing relevant metrics came from the systematic review conducted by González et al. (2010) on the topic of measurements in business processes.

In some scientific papers – for example in (Khlif et al., 2009), (Cardoso et al., 2006), (Cardoso, Vanderfeesten & Reijers, 2010) or (Muketha et al., 2010) – traditional metrics from the field of software engineering are used to cope with the problem of assessing the quality of business process models. In particular, there is a strong analogy between business processes and object-oriented software. This was the reason why Khlif et al. (2009) proposed a set of new metrics for models in BPMN that were based on the original object-oriented metrics. Those metrics can help to obtain more information about categories: complexity, cohesion and coupling of business process models. Also, Cardoso, Vanderfeesten and Reijers (2010) decided to adapt both software and software engineering metrics to business process models. However, these metrics were initially developed to check software quality and so an explanation was needed in order to understand how they can be used to measure process models.

Khlif et al. (2009) presented in a table a grouping of corresponding metrics from the field of object oriented programming and modelling in BPMN. Both fields are similar to each other for a number of reasons. Firstly, since they are based on a compositional structure. This is because the structure in both is based on the composition of the collaborating system (model) components. Secondly, in both fields the information is processed in steps. Programs coded in high level programming languages (e.g. Java, Delphi, C++ or others) are built from packages, modules, functions or procedures that collect predefined data and return expected results. Similarly, business process models are composed of activities that operate on data elements. Finally, in both fields, the dynamic view is derived from the static view. Naturally, there are also big differences between object oriented programming and modeling and some examples can be found in the study of Muketha et al. (2010).

5.4 Metrics for the model quality characteristics

This section assigns the chosen metrics to the developed quality characteristics of models in BPMN (see Section 4). In Section 5.5, the metrics will be described. Some metrics are useful for more than one sub-characteristic. The rationale for choosing them is then provided in Section 5.6.

Sub-characteristics for Syntactic correctness

- Syntactic correctness
  1. Default tool syntax checker (more information in Section 6.1.1).
  2. Additional syntaxes checks build in some more sensitive metrics (more information in Section 5.5 and 6.1.1).
  3. Metrics assigned to the sub-characteristic:
     - Cross-connectivity (CC) metric by Vanderfeesten et al. (2008)
     - Halsted-based Process Complexity metrics (HPC_D, HPC_V, HPC_N) by Cardoso et al. (2006)
- Structural metrics (\(S_n(G), \text{CNC}(G), S(G), d(G)\)) by Mendling (2008) from metrics selected through experiments by Sánchez-González et al. (2010)
- Exported Coupling of a Process (ECP) and Imported Coupling of a Process (ICP) metrics adapted to the business modelling domain by Khlif et al. (2009)
- Coupling metric (CP) by Cardoso, Vanderfeesten and Reijers (2010)

Sub-characteristics for **Modifiability** and the **assigned metrics**:
- **Changeability**
  - Coupling metric (CP) by Cardoso, Vanderfeesten and Reijers (2010)
  - Control-flow Complexity metric (CFC) by Cargoso (2005)
  - Density metric \(d(G)\) and Sequentiality metric \(S(G)\) by Mendling (2008) selected through experiments by Sánchez-González et al. (2010)
  - Halsted-based Process Complexity (HPC_D, HPC_V, HPC_N) by Cardoso et al. (2006)
  - Exported Coupling of a Process (ECP) and Imported Coupling of a Process (ICP) metrics adapted to the business modelling domain by Khlif et al. (2009)

Sub-characteristics for **Complexity** and the **assigned metrics**:
- **Minimality and Simplicity**
  - Fan-in/fan-out (FIO) metric by Gruhn and Laue (2006b)
  - Number of Activities (NOA) and Number of Activities, Joins and Splits (NOAJS) metrics adapted to the business modelling domain by Cardoso et al. (2006)

Sub-characteristics for **Understandability** and the **assigned metrics**:
- **User comprehensibility**
  - Control-flow Complexity metric (CFC) by Cargoso (2005)
  - Cross-connectivity (CC) metric by Vanderfeesten et al. (2008)
  - Number of Activities (NOA) and Number of Activities, Joins and Splits (NOAJS) metrics adapted to the business modelling domain by Cardoso et al. (2006)
  - Fan-in/fan-out metric by Gruhn and Laue (2006b)
  - Number of Nodes (\(S_n(G)\)) metric, Coefficient of Connectivity (CNC(G)) metric and Sequentiality (S(G)) metric by Mendling (2008) selected through experiments by Sánchez-González et al. (2010)
  - Coupling metric (CP) by Cardoso, Vanderfeesten and Reijers (2010)
  - Interface complexity of an activity metric (IC) by Cargoso et al. (2006)
  - Coefficient of network complexity (CNC) by Cargoso et al. (2006)

Sub-characteristics for **Aesthetics of diagrams**
- Coupling metric (CP) by Cardoso, Vanderfeesten and Reijers (2010)
- Exported Coupling of a Process (ECP) and Imported Coupling of a Process (ICP) metrics adapted to the business modelling domain by Khlif et al. (2009)
- Coefficient of network complexity (CNC) by Cargoso et al. (2006)
5.5 Overview of the selected quality metrics

This section summarizes the findings – each metric is presented by giving (1) a short general description, (2) desired value of the metric (or trend), (3) validation of the metric (if available), (4) method of calculating (with definition), (5) metric’s origination (if applicable) and (6) limitation of the (original) metric.

5.5.1 Coupling (CP) metric by Cardoso, Vanderfeesten and Reijers (2010)

Short general description:
The metric calculates the degree of coupling. Coupling is related to the number of interconnections among the tasks of a process model.

Desired value of the metric:
Desired is a low coupling (CP) value. The higher coupling value of the process, the more difficult it is to change the process and the higher probability that there will be errors in the process.

Validation of the metric:
The metric was tested by Cardoso, Vanderfeesten and Reijers (2010) through a set of experiments using several SAP reference models.

Method of calculation:
\[
CP = \frac{\sum_{t_1,t_2 \in T} connected(t_1, t_2)}{|T| \times (|T| - 1)}
\]

\[
connected(t_1, t_2) = \begin{cases} 
1, & \text{if } \left(t_1 \rightarrow t_2 \right) \land \left(t_1 \neq t_2\right) \\
1, & \text{if } \left(t_1 \rightarrow \text{AND} \rightarrow t_2 \right) \land \left(t_1 \neq t_2\right) \\
\frac{1}{m \cdot n}, & \text{if } \left(t_1 \rightarrow \text{OR} \rightarrow t_2 \right) \land \left(t_1 \neq t_2\right) \\
0, & t_1 = t_2
\end{cases}
\]

where
- \(t_1, t_2\) – a connected pair,
- \(t_1 \rightarrow t_2\) – an arc going from \(t_1\) to \(t_2\) between the connected elements,
- \(m\) – number of ingoing branches of a connector,
- \(n\) – number of outgoing branches of a connector,
- \(T\) – total number possible connected pairs (leaving out the pairs that have the same elements connected),

The adaptation of the CP metric by the author of the thesis:
In order to calculate CP metric for real models in BPMN, two additional assumptions were needed:

\(connected(t_1, t_2) = 0\), if \(t_1 \rightarrow \text{other types of gateways} \rightarrow t_2 \land (t_1 \neq t_2)\)

\(connected(t_1, t_2) = 0\), if \((\text{gateway}_1 \rightarrow \text{gateway}_2) \land (\text{gateway}_1 \neq \text{gateway}_2)\)

where
- \(\text{other types of gateways}\) – type of gateway different than AND, OR, XOR

This is a limitation of the CP metric, therefore further research should state the correct method of calculation of other types of gateways for the metric.

60
Origin:
This metric is developed from the density metric proposed by Mendling (2006). Mendling's density metric was designed to measure the complexity of process models. However, Cardoso, Vanderfeesten and Reijers (2010) suggested that the metric actually calculated the degree of coupling.

Limitation of the original metric:
According to Cardoso, Vanderfeesten & Reijers (2010) there are two limitations of Mendling's original density metric: it includes self-loops within activities and it does not consider different connectors, e.g. AND, OR, XOR.

5.5.2 Control-flow Complexity metric (CFC) by Cardoso (2005)

Short general description:
Control-flow Complexity (CFC) is an additive metric proposed by Cardoso (2005). An evaluation of the complexity of the process is carried out using the control-flow behaviour and is affected by split and join constructs. Khlif et al. (2009) summarized the reason for using the metric as enabling an evaluation of the number of possible states that have to be taken into consideration when developing processes. The metric is independent of the language used for modelling and therefore can be used e.g. with BPMN models. For example, Rólón et al. (2009) used the metric to evaluate the control-flow complexity of several models in BPMN.

Desired value of the metric:
Desired is a low CFC complexity value. The greater the overall structural complexity of a process is, the higher the value of the CFC is that will be obtained.

Limitation of the metric:
A limitation of the metric is related to the value obtained as a result of the calculations. Cardoso (2005) recommended that organizations should implement maximal complexity limits on their business process models. He argues that “it may happen that simple processes come to be designed in a complex way”. However, he did not define what he suggests for this limit. Due to the fact that the CFC metric is additive, what should be used as the limit is unclear.

Validation of the metric:
Muketha et al. (2010) summarizes the validation of the metric as follows. The CFC metric was theoretically validated through the use of Weyuker's properties. The results were statistically significant. Additionally, the metric was empirically validated and the results were also statistically significant. In the set of experiments conducted, Spearman's correlation coefficients were used in order to test the hypothesis.

Method of calculation:
The CFC metric counts the values of all splits in the model.

\[
CFC = \sum CFC_{\text{XOR-Split}}(a) + \sum CFC_{\text{OR-Split}}(a) + \sum CFC_{\text{AND-Split}}(a)
\]

where:
- \(a\) – an activity
- \(\text{fan-out}(a)\) – number of transitions going out of an activity
- \(CFC_{\text{XOR-Split}}(a) = \text{fan-out}(a)\)
\[
\text{CFC}_{\text{OR-Split}}(a) = 2^{\text{fan-out}(a)} - 1
\]
\[
\text{CFC}_{\text{AND-Split}}(a) = 1
\]

**Additional assumption by the author of the thesis:**
An additional assumption needed to be made by the author of the thesis in order to meet the requirements of the thesis. Cardoso (2005) distinguished three types of gateways: OR, XOR and AND, and only provided methods of calculations for them. Therefore, other types of gateways (e.g. Complex gateways) in this thesis will have value 0, which does not change the result of calculations of CFC metric. This is a limitation of the CFC metric, therefore further research should state the correct method of calculation of other types of gateways for the metric.

**Origin:**
The Control-flow Complexity metric originates from McCabe's cyclomatic number (McCabe, 1976). Both metrics differ in the context of calculating and treatment of decision nodes. In CFC, nodes have different semantics while in the McCabe's cyclomatic metric all nodes are treated equally.

### 5.5.3 Cross-connectivity (CC) metric by Vanderfeesten *et al.* (2008)

**Short general description:**
The Cross-connectivity (CC) metric is designed to measure the strengths of the arcs between the nodes of models. It aims to capture the cognitive effort to understand the relationship between any pair of process model elements. The CC metric expresses the sum of connectivity between all pairs of nodes in a process model relative to the theoretical maximum number of paths between all nodes. The path with the highest connectivity between two nodes determines the strength of the overall connectivity of these nodes.

**Desired value of the metric:**
Desired is a high CC value. The more difficult it is to understand the model, the lower the CC value is assigned to the model. In accordance with Vanderfeesten *et al.* (2008), models with low cross-connectivity values are more likely to include errors.

**Validation of the metric:**
The metric was empirically evaluated for understandability and additionally the EPC soundness criterion was used to determine whether a decrease in the metric's value implies an increase in error probability (Vanderfeesten *et al.*, 2008).

**Method of calculation:**
\[
CC = \frac{\sum_{n_1,n_2 \in N} V(n_1, n_2)}{|N| \cdot (|N| - 1)}
\]
where
- \(T\) – set of tasks
- \(C\) – set of connectors
- \(N\) – set of nodes (\(N = T \cup C\))
- \(A\) – set of directed arcs
- \(P_{n_1,n_2}\) – set of paths from node \(n_1\) to \(n_2\)
d – a degree of the node (i.e. the total number of ingoing and outgoing arcs of the node)
w(n) – weight of a node n
W(a) – the weight of arc a
src(a) – a source node
dest(a) – a destination node
p – path from node n₁ to n₂; path is given by the sequence of directed arcs that should be followed from n₁ to n₂: p = <a₁, a₂, ..., aₙ>.
v(p) – a value of a path p
V(n₁, n₂) – a value of the connection from n₁ to n₂

sub-defined

\[ w(n) = \begin{cases} 
1, & \text{if } n \in C \land n \text{ is of type AND} \\
\frac{1}{a}, & \text{if } n \in C \land n \text{ is of type XOR} \\
\frac{1}{2^{a-1}} + \frac{2^{a-2}}{2^{a-1}}, & \text{if } n \in C \land n \text{ is of type OR} \\
1, & \text{if } n \in T
\end{cases} \]

\[ W(a) = w(\text{src}(a)) \cdot w(\text{dest}(a)) \]

\[ v(p) = W(a₁) \cdot W(a₂) \cdot ... \cdot W(aₙ) \]

\[ V(n₁, n₂) = \begin{cases} 
0, & \text{if no path exists between node } n₁ \text{ and } n₂ \\
\max_{p \in P_{n₁, n₂}} v(p), & \text{otherwise}
\end{cases} \]

The CC metric is very sensitive to the syntactic correctness of the BPMN model. Therefore, the author of the thesis extracted a list of additional assumptions that should be taken into consideration before the algorithm can be calculated:

1. When considering the metric, Vanderfeesten et al. (2008) did not take into account BPMN models with events and how it will influence the results. In BPMN it is hard to model without events. Therefore, for different types of events (start events, end events and intermediate events) the author of the thesis assumed that the weight of node is equal 0. Further research should provide information if this value should be different or if there should be a spectrum of weights for different event nodes.

2. When Vanderfeesten et al. (2008) considered the metric, they distinguished only three types of gateways: OR, XOR and AND, and only provided methods of calculating weights for them. Therefore without further research, BPMN models with other than types of gateways (e.g. Complex gateways) cannot be calculated using the CC metric.

3. In addition, if a BPMN model contains a syntactically incorrect arc (e.g. flow with no source or terminal task, etc.), the CC metric cannot be calculated (see example in Figure 5.2 below). The correct arc in BPMN needs to start and end on diagram element and can connect only two elements.

**Figure 5.2.** Example of an incorrect arc element in BPMN.
4. The CC metric cannot calculate business process models smaller than having two elements, e.g. two tasks. However, smaller models would also not be compliant with the BPMN specification.

5. Vanderfeesten et al. (2008) noted that in the algorithm used for the calculation of the metric “loops in a path should not be considered more than once, since the value of the connection will not be higher if the loop is followed”. This can be understood in a few ways; therefore the following interpretation of paths was adopted by the author of the thesis in the metric's implementation. Using Figure 5.3 as an example, all possible paths in the BPMN model are:

   A (start) → AND (stop)
   A (start) → AND → OR (stop)
   A (start) → AND → OR → B (stop)
   A (start) → AND → OR → AND (stop)
   AND (start) → OR (stop)
   AND (start) → OR → B (stop)
   AND (start) → OR → AND (stop)
   OR (start) → B (stop)
   OR (start) → AND (stop)
   OR (start) → AND → OR (stop)

![Figure 5.3](image)

**Figure 5.3.** Example of a BPMN model used to explain the interpretation of loops in the implementation of the CC metric.

**Limitation of the metric:**

1. The metric is based on the following assumptions:
   - The process model in BPMN consists of tasks and connectors.
   - Tasks have at most one input and output arc while connectors can have multiple input and output arcs.
   - Understanding the relationship between a pair of elements can only be as easy as the most difficult part.
2. A single weak link affects the entire connection.
5.5.4 Exported Coupling of a Process (ECP) and Imported Coupling of a Process (ICP) metrics adopted to the business modelling domain by Khlif et al. (2009)

*Short general description:*
According to Khlif *et al.* (2009) “coupling in business process models (BPM) focuses on how strongly the activities in a business process are related, or connected to each other. An activity is connected to another activity if and only if they share one or more information elements”. The measures examine the importance of the activities in the models.

*Desired value of the metrics:*
Desired is a low value of ICP metric. The higher the ICP value, the more dependent is the process on services offered by other processes.

Desired is a low value of ECP metric. The higher the ECP value, the more other processes depend on the services of the process.

*Validation of the metrics:*
Information not found.

*Method of calculation:*
Imported Coupling of a Process (ICP) – the metric counts for each task or sub-process, the number of message/sequence flows sent by the task or the sub-process.

*The adaptation of the ICP metric by the author of the thesis:*
In order that the ICP value is correctly calculated for models in BPMN, the author of the thesis thinks that associations and data associations should be included. Following the specification (BPMN, 2011), there are four ways of connecting the flow objects to each other or other information in BPMN. These are: sequence flows, message flows, associations and data associations. Therefore the adapted EPC metric counts sent message flows, sequence flows, associations and data associations.

The greatest ICP value obtained for any of the business process model’s tasks or sub-processes was used as the ICP metric value for the whole model.

Exported Coupling of a Process (ECP) – for each task or sub-process the metric counts the number of message/sequence flows received by either the task or the sub-process.

*The adaptation of the ECP metric by the author of the thesis:*
The author of the thesis adapted the ECP metric in order to meet the needs of the thesis. In order to properly calculate the ECP values for a model in BPMN, associations and data associations should also be included. Following the specification (BPMN, 2011), in BPMN there are four ways of connecting the flow objects to each other or other information. These are: sequence flows, message flows, associations and data associations. Therefore, the adapted EPC metric counts received message flows, sequence flows associations and data associations.

In order to collect the value of the ECP for the whole business process model, the greatest ECP value obtained by any of its tasks or sub-processes is used.
Origin:
Khlif et al. (2009) proposed the adaptation of the Imported Coupling (IC) and Exported Coupling (EC) metrics from the object-oriented software engineering domain to be used in the context of BPMN modelling.

ICP originates form the Imported Coupling (IC) metric. The IC metric “counts for each class C, all interactions in which C uses another class” (Khlif et al., 2009).

ECP originates form the Exported Coupling (EC) metric. The EC metric “counts for each class C, all interactions in which C is used” (Khlif et al., 2009).

Limitation of the metrics:
The coupling metrics do not provide the information about the dependency of activities in terms of data usage because they only focus on the data interchange (Khlif et al., 2009).

5.5.5 Cognitive Complexity (W) Measure by Gruhn and Laue (2006a)

Short general description:
In (Gruhn & Laue, 2006a), a cognitive weight is proposed to measure the effort needed for comprehending the model.

Desired value of the metrics:
Desired is a low value for cognitive weight (W) metric. The higher the W value, the more difficult it is to understand the model.

Validation of the metrics:
Metric has not been validated (Muketha et al., 2010).

Method of calculation:
The cognitive weight of the model (W) is the sum of the cognitive weights of its individual elements.

Cognitive weights of business process model elements are proposed by Gruhn and Laue (2006a) for the YAWL language. Therefore the author of the thesis used the definitions to propose adequate cognitive weights for BPMN models (Table 5.1).

<table>
<thead>
<tr>
<th>BPM control structure</th>
<th>Corresponding software control structure</th>
<th>Example of relevant BPMN symbol</th>
<th>Cognitive weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>single consecutive step in a work-flow</td>
<td>sequence</td>
<td><img src="image" alt="Task-Task2-Task3" /></td>
<td>1</td>
</tr>
<tr>
<td>joins (only if the relationship value of the join equals 1)</td>
<td>none</td>
<td><img src="image" alt="Task2-Gateway-Task3" /></td>
<td>1</td>
</tr>
<tr>
<td>XOR-split (exactly one of two branches is chosen)</td>
<td>branching with if-then</td>
<td><img src="image" alt="Gateway" /></td>
<td>2</td>
</tr>
<tr>
<td>Type of Split</td>
<td>Description</td>
<td>Cognitive Weight</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>XOR-split</td>
<td>(exactly one of more than two branches is chosen)</td>
<td>branching with case (with an arbitrary number of selectable cases)</td>
<td>3</td>
</tr>
<tr>
<td>AND-split</td>
<td></td>
<td>execution of control flows in parallel</td>
<td>4</td>
</tr>
<tr>
<td>OR-split, complex decision/merge</td>
<td></td>
<td>branching with a case followed by parallel execution</td>
<td>7</td>
</tr>
<tr>
<td>Sub-Process (can be used for decomposing the BPMN model)</td>
<td></td>
<td>call a user-defined function</td>
<td>2</td>
</tr>
<tr>
<td>Start or end event</td>
<td></td>
<td>comparable to a function call</td>
<td>2</td>
</tr>
<tr>
<td>Intermediate event (both intermediate events attached to the boundary of activities and intermediate events within the normal flows)</td>
<td></td>
<td>comparable to a function call</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 5.1. Cognitive weights for elements in BPMN.

**Origin:**

**Limitation of the metric:**
The cognitive weight of the model (W) metric is defined by Gruhn and Laue (2006a) only for business process models that are well-structured. In BPMN, corresponding joins are not necessary. Therefore, to adapt the metric to BPMN, the author of the thesis considered the weight of join elements equal to the cognitive weight of sequence elements.

5.5.6 Fan-in/fan-out metric by Gruhn and Laue (2006b)

**Short general description:**
Metrics proposed by Gruhn and Laue (2006b) can be used to analyse the complexity of business process models based on modular structure. Modular modeling is supported in BPMN by sub-processes. The metric is similar to metric proposed by Khelif et al. (2009); however it does not include length.

Further metrics proposed in the study of Gruhn and Laue (2006b) are related to other works and therefore are not cited here (e.g. Cargoso et al. (2006) – NOA, NOAJS; Cardoso (2005) – CNC metric).

**Desired value of the metric:**
Desired is low value of fan-in/fan-out metric.
The higher structural complexity of a model or sub-model according to the fan-in/fan-out value, the more difficult model is to be used and the more likely it is badly designed.

*Validation of the metric:*  
The metric has not been validated (Muketha et al., 2010). According to González et al. (2010) the validation in the case study of the metric proposed by Gruhn and Laue (2006b) must be carried out in future research.

*Method of calculating:*  
\[ FIO = (\text{fan-in} \cdot \text{fan-out})^2 \]  
where  
- \( \text{fan-in} \) – is a count of all other elements that call sub-process,  
- \( \text{fan-out} \) – is a count of all other elements that are called from sub-process.

*The adaptation of the FIO metric by the author of the thesis:*  
Metric proposed by Gruhn and Laue (2006b) takes into consideration only sub-processes in BPMN (it does not count tasks). Therefore if no sub-processes are in the model, the FIO value equals 0 (assumption).

The FIO metric value of the whole business process will be taken from the greatest FIO value obtained by any of its sub-processes.

*Origin:*  
In (Gruhn & Laue, 2006b), the fan-in/fan-out metric is based on a metric for the complexity of software proposed by Henry and Kafura (1981).

*Limitation of the metric:*  
From the definition of the metric it is not clear what should be adopted if the model does not have a modular structure. Therefore, if the model does not have sub-processes, the author of the thesis assumed that FIO value equals zero.

5.5.7 Number of Activities (NOA) and Number of Activities, Joins and Splits (NOAJS) complexity metrics adopted to business modelling domain by Cardoso et al. (2006)

*Short general description:*  
The Number of Activities (NOA) and Number of Activities, Joins and Splits (NOAJS) metrics are very simple and popular. They can be used to measure complexity in business process models. NOA metric sums up activities in business process model (Cardoso et al. 2006). In BPMN, splits do not necessary have corresponding joins. Cardoso et al. (2006) named these processes as “not well-structured” and proposed an additional measure for them (NOAJS), based on counting activities, joins and splits together.

*Desired value of the metrics:*  
Desired is a low value of NOA and NOAJS metrics.

*Validation of the metric:*  
Metrics have not been validated (Muketha et al., 2010).
**Method of calculating:**

NOA ≡ Total number of activities

NOAJS ≡ Total number of activities, joins and splits

In BPMN, an activity can be atomic (known as a Task) or compound (called Sub-Process). Therefore, in NOA and NOAJS metrics, both kinds of activities will be calculated together.

**Origin:**
The NOA and NOAJS metrics originate from the LOC (Lines of Code) software metric adapted to measure models. LOC metric “counts the lines of executable code, data declarations, comments and so on” (Cardoso et al., 2006) in programs.

It originates from the assumption that “program length can be used as a predictor of program characteristics such as errors occurrences, reliability, and ease of maintenance” (Cardoso et al., 2006). Additionally, Cardoso et al. (2006) explained that LOC “has been shown to be very useful and correlates well with the number of errors in programs”. According to Cardoso et al. (2006) the NOA metric is easier for users to understand than LOC because it is not language dependent.

**Limitation of the original metric:**
Khlif et al. (2009) provided the information that LOC has been criticized as being too limited in order to measure complexity. For example, the metric takes into account only length which is only one view of size and it does not take into consideration functionality.

5.5.8 Halsted-based Process Complexity (HPC) by Cardoso et al. (2006)

**Short general description:**
Cardoso et al. (2006) proposed quantitative measures of complexity aimed to calculate the length of the process, its volume and difficulty. Specifically, they map business process elements to the set of primitive measures proposed by Halsted (1987). The metrics can be used for most languages of process modelling (Cardoso et al., 2006), and therefore can be used for models in BPMN.

**Desired value of the metrics:**
Desired is low value for the Halsted-based Process Complexity (HPC) metric. Cardoso et al. (2006) admitted that the measurement require calibration that should be investigated with empirical experiments.

**Validation of the metric:**
The metrics have not been validated (Muketha et al., 2010).

**Method of calculating:**

\[ D = \left( \frac{n_1}{2} \right) \cdot \left( \frac{N_2}{n_2} \right) \]

\[ N = n_1 \cdot \log_2(n_1) + n_2 \cdot \log_2(n_2) \]

\[ V = (N_1 + N_2) \cdot \log_2(n_1 + n_2) \]
where

\[ D - \text{process difficulty}, \]
\[ N - \text{process length}, \]
\[ V - \text{process volume}, \]
\[ n_1 - \text{the number of unique activities, splits, joints and control-flow elements} \]
\[ n_2 - \text{the amount of unique data that is manipulated by the process and its activities}, \]
\[ N_1 \text{ and } N_2 - \text{process lengths derived from } n_1 \text{ and } n_2. \]

*The adaptation of the HPC metrics by the author of the thesis:*

Cardoso *et al.* (2006) did not formalize HPC measurements which require calibration before they are used. Due to this fact, the formalization of the metrics for BPMN is provided below:

\[ n_3 - \text{the number of unique data objects, data inputs, data outputs and data stores (duplicates removed)}. \]
\[ N_1 - \text{number of unique types of activities and control-flow elements used in the BPMN model – e.g. task, sub-process, XOR gateway, OR gateway, etc.} \]
\[ N_2 - \text{number of unique data types used in the BPMN model – data objects, data inputs, data outputs and data stores.} \]

Additionally, the author of the thesis assumes that the D value cannot be calculated if \( n_2 \) equals 0. Moreover, the N metric can be calculated only if \( n_2 > 0 \) and \( n_1 > 0 \) and the V metric can be calculated only if \( n_2 + n_1 > 0 \), otherwise they cannot be calculated (this is because the log value is undefined).

*Origin:*
The metrics are based on the set of primitive measures that may be derived from the source code proposed by Halstead (1987). That is, the metric based on interpreting the source code as a sequence of tokens that are classified to be an operator or an operand.

### 5.5.9 Interface Complexity (IC) of an activity metric by Cargoso *et al.* (2006)

*Short general description:*
The Interface Complexity (IC) metric can be used to evaluate the complexity of processes.

*Desired value of the metric:*
Desired is a low value of IC metric.

*Validation of the metric:*
The metric has not been validated (Muketha *et al.*, 2010).

*Method of calculating:*
\[
\text{IC} = \frac{\text{length}}{(\text{number of inputs} \cdot \text{number of outputs})^2}
\]

where
- *inputs* – incoming data flows of an activity,
- *output* – outgoing data flows of an activity.

In BPMN as an activity, tasks and sub-processes will be taken into account.
The adaptation of the length value by the author of the thesis:
It is not clear how length should be calculated for BPMN models. Therefore, in this thesis it will be calculated as follows:
length = 1, for task (task considered as a black box),
length = 3, for sub-process (representing the sub-process as a collection of activities, further research should propose a more accurate value).

The adaptation of the IC value by the author of the thesis:
As an IC metric value of the whole business process will be taken, the sum of the IC values obtained by its activities will be used.

Origin:
Khlf et al. (2009) point out that the information flow metric proposed by Henry and Kaufura (1981) was the origin of the IC metric, which can measure the complexity of models. After the metric was adapted to the business process domain, the metric by Henry and Kaufura (1981) was based on the impact of the information flow on a program's structure.

Limitation of the original metric:
The metric can give the result zero as the value of complexity if an activity has no external interactions. For example, for the end activities of the processes.

5.5.10 Structural metrics by Mendling (2008) from metrics selected through experiments by Sánchez-González et al. (2010)

Short general description:
Mendling (2008) proposed a group of structural metrics that can be used to measure business process models. Later, some of these metrics were selected through experiments by Sánchez-González et al. (2010) as having best results for modifiability or understandability. Experiments were based on the BPMN models.

Related work: Coefficient of network complexity (CNC) is a simple metric for the complexity of a graph. This metric is also introduced by Cargoso et al. (2006) and discussed in (Latva-Koivisto, 2001).

Desired value of the metric:
Desired is low value of Sn(G) metric.
The higher Sn(G) value, the more likely it is to have errors in the overall model.

Desired is low value of CNC(G) metric.
The higher CNC(G) value, the more likely it is to have errors in the overall model.

Desired is high value of S(G) metric.
The higher S(G) value, the less likely it is to have errors in the overall model.

Desired is low value of d(G) metric.
The higher d(G) value, the more likely it is to have errors in the overall model.

Validation of the metric:
Experiments carried out by Sánchez-González et al. (2010) showed the usefulness of some metrics proposed by Mendling (2008). However, the metrics have not been validated (Muketha et al., 2010).
Method of calculating:
The metrics are based on the consideration that a business process model is a special kind of graph \( G=(N, A) \), \( N \) – nodes, \( N = T \cup S \cup J \) (\( T \) – tasks, \( S \) – splits, \( J \) – joints); \( A \) – control flow arcs (\( A \subseteq N \times N \)).

Number of Nodes \( S_n(G) = N \) (number of nodes of the process model graph)

Coefficient of Connectivity \( CNC(G) = \frac{A}{N} \)

Sequentiality \( S(G) = \frac{A \cap (T \times T)}{A} \)

Density \( d(G) = \frac{A}{N \cdot (N - 1)} \)

Limitation of the metrics:
Numbers of Nodes \( S_n(G) \) metric – some kinds of large BPMN models are very unlikely to have errors (for example basic sequential BPMN models). Additionally, the metric does not differentiate between types of nodes.

Coefficient of Connectivity \( CNC(G) \) metric – models in BPMN with the same result of the metric may differ in the error probability. Moreover, it is possible to create BPMN models that vary in their difficulty level and contain an equal number of arcs and number of activities, joins, and splits.

Sequentiality \( S(G) \) metric – models in BPMN with the same result of the metric may differ in their degree of comprehensibility.

Density \( d(G) \) metric – not easy to compare for BPMN models with differing number of nodes.

5.6 Rationale for assigning metrics to sub-characteristics

In this section each metric will be presented along with an explanation for each sub-characteristic it is assigned to. The relevance of quality metrics to quality sub-characteristics in the thesis is derived from the literature where the metrics were found. The quality sub-characteristics used are based on a systematic literature review (see Section 4). Next, using a literature review of quality metrics based on selection criteria found in Section 5.2 metrics were selected from literature. As a result, these quality metrics are then assigned to sub-characteristics in the following sections (see Sections 5.6.1-5.6.10).

5.6.1 Coupling metric (CP) by Cardoso, Vanderfeesten and Reijers (2010)

_Coupling metric by Cardoso, Vanderfeesten and Reijers (2010)_ is selected to measure:

- Sub-characteristic of Understandability: **User comprehensibility**
  According to Cardoso, Vanderfeesten and Reijers (2010) high complexity in process may result in bad understandability. Therefore, process complexity should be kept in low level.
- Sub-characteristic of Modifiability: **Changeability**
  In accordance with Cardoso, Vanderfeesten and Reijers (2010), the lower value of coupling (and the metric), the easier to change the process.

- Sub-characteristic of Understandability: **Aesthetics of models**
  In accordance with Cardoso, Vanderfeesten and Reijers (2010), business process models with high coupling CP metric have complicated connections. This can be reflected in the organization of BPMN models.

- Sub-characteristic of Correctness: **Syntactic correctness**
  CP metric can predict rate of errors. According to Cardoso, Vanderfeesten and Reijers (2010) high complexity in process may result in errors, defects and exceptions, leading processes to need more time to develop, test and maintain.

5.6.2 Control-flow Complexity metric (CFC) by Cardoso (2005)

*Control-flow Complexity metric (CFC) by Cardoso (2005)* is selected to measure:

- Sub-characteristic of Understandability: **User comprehensibility**
  It is easier to understand and maintain business process models which have low complexity. Rolón *et al.* (2009) explained that “business processes should minimize their complexity in order to provide adequate support to the various stakeholders”. Additionally, according to González *et al.* (2010) the metric is suitable to measure understandability.

- Sub-characteristic of Modifiability: **Changeability**
  Following Rolón *et al.* (2009), models with reasonable complexity are easier to modify and maintain. The metric may help to develop simpler processes when it is possible. Additionally, according to González *et al.* (2010) the metric is suitable to measure changeability.

5.6.3 Cross-connectivity (CC) metric by Vanderfeesten *et al.* (2008)

*Cross-connectivity (CC) metric by Vanderfeesten *et al.* (2008)* is selected to measure:

- Sub-characteristic of Correctness: **Syntactic correctness**
  CC metric can predict rate of error. Vanderfeesten *et al.* (2008) described that models with a high cross-connectivity contain less syntactic errors.

- Sub-characteristic of Understandability: **User comprehensibility**
  Vanderfeesten *et al.* (2008) argued that models with a high cross-connectivity can facilitate understanding of business processes among various stakeholders.
5.6.4 Exported Coupling of a Process (ECP) and Imported Coupling of a Process (ICP) metrics by Khlif et al. (2009)

A set of coupling metrics adapted to business modelling domain by Khlif et al. (2009) is selected to measure:

- **Sub-characteristic of Modifiability: Changeability**
  The use of the ICP and ECP metric – According to Khlif et al. (2009) business process models that have high coupling metric, have “a high level of informational dependency between its activities” so they are difficult change or maintain and should be avoided or at least treated with special attention.

- **Sub-characteristic of Correctness: Syntactic correctness**
  The use of the ICP and ECP metric – ICP and ECP metric can predict rate of errors. according to Khlif et al. (2009) a process with a high ECP influences whole model because multitude of processes depends on its services. And models with processes that have a high ICP value may have error probability increased because they depend on several services offered by other processes.

- **Sub-characteristic of Understandability: Aesthetics of models**
  The organization of BPMN models with high ICP or ECP metrics may be not clear and thous difficult to understand. The coupling metric detects models in which multiple processes depend on each other what may influence on the look of the whole design.

5.6.5 Cognitive Complexity Measure by Gruhn and Laue (2006)

*Cognitive Complexity Measure by Gruhn and Laue (2006)* is selected to measure:

- **Sub-characteristic of Understandability: User comprehensibility**
  Following (Gruhn & Laue, 2006), the complexity measures can state whether models are easy to understand. Additionally, according to González et al. (2010) the metric is suitable to measure understandability.

- **Sub-characteristic of Modifiability: Changeability**
  According to González et al. (2010) the metric is suitable to measure changeability.

5.6.6 Fan-in/fan-out metric by Gruhn and Laue (2006b)

Fan-in/fan-out (FIO) metric by Gruhn and Laue (2006b) is selected to measure:

- **Sub-characteristic for Understandability: User comprehensibility**
  FIO metric that can provide some information about understandability of the BPMN model. Following Gruhn and Laue (2006b), modular sub-processes can help to make the model easier to comprehend.

- **Sub-characteristic for Modifiability: Reusability and extensibility**
  In accordance with Gruhn and Laue (2006b) FIO metric detect poor modularization. If modularization is used in a reasonable way, dividing model in modular sub-models can lead to smaller, reusable models.
- Sub-characteristic for Complexity: **Minimality and Simplicity**

  Following (Gruhn & Laue, 2006b), if the examined sub-process in the model has both large fan-in and fan-out, this may indicate that the model has not an appropriate size or was partitioned into modules not in a sensible way. Re-design in this situation could improve the sub-process.

### 5.6.7 Number of Activities (NOA) and Number of Activities, Joins and Splits (NOAJS) metrics by Cardoso et al. (2006)

*NOA and NOAJS complexity metrics adapted to business modelling domain by Cardoso et al. (2006) are selected to measure:*

- Sub-characteristic of Understandability: **Minimality and simplicity**
  
  In accordance with (Khlif et al., 2009), these simple metrics may show models that are badly designed with an excessive number of activities.

- Sub-characteristic of Understandability: **User comprehensibility**
  
  Metrics may provide some information about the understandability of designs.

### 5.6.8 Halsted-based Process Complexity (HPC) by Cardoso et al. (2006)

*Halsted-based Process Complexity (HPC) by Cardoso et al. (2006) is selected to measure:*

- Sub-characteristic of Correctness: **Syntactic correctness**
  
  Following Cardoso et al. (2006) the HPC metric can predict rate of errors.

- Sub-characteristic of Modifiability: **Changeability**
  
  Following Cardoso et al. (2006) the HPC metric can predict maintenance effort.

### 5.6.9 Interface complexity of an activity metric (IC) by Cargoso et al. (2006)

*Interface complexity of an activity metric (IC) by Cargoso et al. (2006) is selected to measure:*

- Sub-characteristic for Understandability: **User comprehensibility**
  
  IC metric it is a measure of complexity of process models. It can provide some information about understandability of the BPMN model.
5.6.10 Structural metrics by Mendling (2008) selected through experiments by Sánchez González et al. (2010)

Structural metrics by Mendling (2008) selected through experiments by Sánchez-González et al. (2010) are selected to measure:

- Sub-characteristic of Understandability: **User comprehensibility**
  Experiments conducted by Sánchez-González et al. (2010) showed that Number of Nodes metric, Coefficient of Connectivity metric and Sequentiality metric seem to be closely with user's understandability. Additionally, following González et al. (2010), the CNC metric is useful to assess understandability.

- Sub-characteristic of Modifiability: **Changeability**
  Experiments conducted by Sánchez-González et al. (2010) showed that Density metric and Sequentiality metric by Mendling (2008) seem to be closely with modifiability. Additionally, following González et al. (2010), the CNC metric is useful to assess changeability.

- Sub-characteristic for Correctness: **Syntactic correctness**
  Structural metrics by Mendling (2008) can predict rate of error. They help to estimate if BPMN models are more likely to have errors.

- Sub-characteristic of Understandability: **Aesthetics of diagrams**
  Following Cargoso et al. (2006) in formal aesthetics the CNC coefficient is considered with the notion of elegance.

5.7 **Summary of metrics**

Table 5.2 gathers all selected metrics from the literature providing symbols, names of metrics and their authors. Additional column shows all adjustments or changes that were necessary to be done by the author of the thesis in order to use the metric for models in BPMN.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name of the metric</th>
<th>Author</th>
<th>Adjustments or changes needed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>Coupling metric</td>
<td>Cardoso, Vanderfeesten and Reijers (2010)</td>
<td>Yes, in order to calculate real examples of BPMN models, it was required to add two additional assumptions to the metric.</td>
</tr>
<tr>
<td>CC</td>
<td>Cross-connectivity metric</td>
<td>Vanderfeesten <em>et al.</em> (2008)</td>
<td>Yes, the CC metric is very sensitive on the syntactic correctness of the BPMN model. Therefore, the author of the thesis extracted a list of additional assumptions that should be taken into consideration before the algorithm could be calculated on realistic BPMN models.</td>
</tr>
<tr>
<td>Metric</td>
<td>Description</td>
<td>Source</td>
<td>Proposal and Calculation Details</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ICP</td>
<td>Imported Coupling of a Process metric</td>
<td>Khlif et al. (2009)</td>
<td>Yes, metric value for the whole business process was proposed. Additionally, following the specification (BPMN, 2011), the author of the thesis thinks that to the proper calculation of the ICP values for models in BPMN, associations and data associations should also be included. Therefore the changed metric counts sent message flows, sequence flows and associations to objects.</td>
</tr>
<tr>
<td>ECP</td>
<td>Exported Coupling of a Process metric</td>
<td>Khlif et al. (2009)</td>
<td>Yes, metric value for the whole business process was proposed. Additionally, following the specification (BPMN, 2011), the author of the thesis thinks that to the proper calculation of the ICP values for models in BPMN, associations and data associations should also be included. Therefore the changed metric counts sent message flows, sequence flows and associations to objects.</td>
</tr>
<tr>
<td>W</td>
<td>Cognitive Complexity Measure</td>
<td>Gruhn and Laue (2006a)</td>
<td>Yes. Cognitive weights of business process model elements by Gruhn and Laue (2006a) were proposed for the YAWL language. Therefore the author of the thesis based on the definitions, proposed adequate cognitive weights for BPMN models.</td>
</tr>
<tr>
<td>FIO</td>
<td>Fan-in/fan-out metric</td>
<td>Gruhn and Laue (2006b)</td>
<td>Yes, metric value for the whole business process was proposed.</td>
</tr>
<tr>
<td>NOAJS</td>
<td>Complexity metric</td>
<td>Cardoso et al. (2006)</td>
<td>No.</td>
</tr>
<tr>
<td>NOA</td>
<td>Complexity metric</td>
<td>Cardoso et al. (2006)</td>
<td>No.</td>
</tr>
<tr>
<td>HPC_D</td>
<td>Halsted-based Process Complexity (process difficulty)</td>
<td>Cardoso et al. (2006)</td>
<td>Yes. Cardoso et al. (2006) did not formalize HPC measurements which require calibration before they are used. Due to this fact, the proposition of formalization of the metrics for BPMN was provided by the author of the thesis.</td>
</tr>
<tr>
<td>HPC_N</td>
<td>Halsted-based Process Complexity (process length)</td>
<td>Cardoso et al. (2006)</td>
<td>Yes. Cardoso et al. (2006) did not formalize HPC measurements which require calibration before they are used. Due to this fact, the proposition of formalization of the metrics for BPMN was provided by the author of the thesis.</td>
</tr>
<tr>
<td>HPC_V</td>
<td>Halsted-based Process Complexity (process volume)</td>
<td>Cardoso et al. (2006)</td>
<td>Yes. Cardoso et al. (2006) did not formalize HPC measurements which require calibration before they are used. Due to this fact, the proposition of formalization of the metrics for BPMN was provided by the author of the thesis.</td>
</tr>
</tbody>
</table>
| IC       | Interface complexity of an activity metric       | Cargoso et al. (2006)        | Yes, metric value for the whole business process was proposed. Additionally, the way of calculating length in the metric was proposed (from the definition it was not
clear how it should be calculated for BPMN models).

<table>
<thead>
<tr>
<th>Sn(G)</th>
<th>Number of Nodes structural metric</th>
<th>Mendling (2008)</th>
<th>No.</th>
</tr>
</thead>
</table>

**Table 5.2.** Details of the chosen metrics.
6 TOOL AND REPOSITORY OF BPMN MODELS

6.1 Repository of BPMN models

In order to obtain a significant repository of BPMN models, the author of the thesis searched the Internet. The models in BPMN were gathered from a few sources (see Table 6.1.) and were used in this research. The found BPMN models had different quality in different sources because they were created by different users with different level of experience in BPMN. Unfortunately, some of the available models in BPMN were impossible to be read (file errors or BPMN models were created in tools not available for the author of the thesis). Therefore in the Table 6.2. the real number of the obtained BPMN models is presented (in total 57 models). The gathered repository of BPMN models was later examined with the implemented tool (see Section 6.2).

At the beginning, the big obstacle appeared: the format of the gathered files. The files were in different formats and the Business Process Visual ARCHITECT accepts only .vpp format and .xml format with a specific and strict structure. Unfortunately, the author of the thesis could not find any working converter of the files. Therefore, the models in BPMN were manually transferred into the .vpp format. The author of the thesis endeavoured to redraw models in BPMN with preserving the original appearance of the models and even all originally conducted mistakes. In order to make this research fully repeatable, BPMN model numbers (identifiers), name and format of the original models are available in the Appendix C.

<table>
<thead>
<tr>
<th>Source number</th>
<th>Source name and description</th>
<th>Source link</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>OMG examples</td>
<td><a href="http://www.omg.org/spec/BPMN/2.0/examples/ZIP/">http://www.omg.org/spec/BPMN/2.0/examples/ZIP/</a> (Accessed: 20.05.2012)</td>
</tr>
</tbody>
</table>

Table 6.1. Sources of BPMN models for the repository.
<table>
<thead>
<tr>
<th>Source number</th>
<th>Number of the available BPMN models in a source</th>
<th>Number of the chosen BPMN models from the source</th>
<th>File format</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10 folders with 23 models</td>
<td>19 models</td>
<td>.bpmn, .vsd</td>
</tr>
<tr>
<td>S2</td>
<td>15 models</td>
<td>10 models</td>
<td>.bpmn</td>
</tr>
<tr>
<td>S3</td>
<td>18 models</td>
<td>17 models</td>
<td>.bpmn</td>
</tr>
<tr>
<td>S4</td>
<td>5 models</td>
<td>5 models</td>
<td>.bpmn</td>
</tr>
<tr>
<td>S5</td>
<td>Approximately 20 models, however in this blog more models can be posted in every time.</td>
<td>6 models</td>
<td>.adf</td>
</tr>
</tbody>
</table>

Total: 57 models

Table 6.2. Details of BPMN models in sources.

Table 6.3 presents quality and complexity of BPMN models from different sources, assessed by the author of the thesis, in order to show that sources contain BPMN models of different quality.

<table>
<thead>
<tr>
<th>Source number</th>
<th>Quality of BPMN models from the source</th>
<th>Complexity of BPMN models from the source</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>High quality.</td>
<td>Mostly middle-high complexity. However some models in the source are intended to show just a single BPMN concept, therefore are very basic.</td>
</tr>
<tr>
<td>S2</td>
<td>Middle-low quality; some BPMN models contain syntactic errors, and they cannot be opened correctly.</td>
<td>Middle complexity.</td>
</tr>
<tr>
<td>S3</td>
<td>Middle quality.</td>
<td>Rather middle complexity.</td>
</tr>
<tr>
<td>S4</td>
<td>High quality.</td>
<td>Middle complexity.</td>
</tr>
<tr>
<td>S5</td>
<td>Rather middle-low quality (BPMN models created by different users, therefore with different quality).</td>
<td>Rather high complexity.</td>
</tr>
</tbody>
</table>

Table 6.3. Quality and complexity of BPMN models in different sources.

### 6.2 Why tool is important

In the thesis the tool is a plug-in that was implemented to the Business Process Visual ARCHITECT (Simulacian) – a well-known software for modelling in BPMN. The plug-in was tested in the version 4.0 of the software, which was available for the author of the thesis. The tool was implemented in Java language\(^\text{13}\).

The tool was important for the thesis because it helped in few stages, of which the most important was to gather data needed to propose quality criteria for metrics (see Section 7) and to compare MAQ with the results of the survey (see Section 9). Quality criteria for metrics were based on the results obtained from measuring BPMN models from the repository, which then was recorded and analysed statistically.

\(^{13}\) Java Language and Virtual Machine Specifications can be found in: http://docs.oracle.com/javase/specs/.
in order to collect more information about ranges of metrics, their distributions and overall trends (see Section 7.1). Having this knowledge and previous reviews of the literature, quality criteria for metrics were proposed.

Manual measuring of metrics for each BPMN model from the repository would be a time-consuming process which without the tool could not be done reasonably. Even manual calculations of one more complex BPMN model are burdened with the risk and probability of miscalculation. This is especially because some metrics are very complicated to calculate manually, for example: Cross-connectivity (CC) metric by Vanderfeesten et al. (2008). Additionally, tool can guarantee the correctness of measurements and reliability of the results. Therefore a tool to help in this process was implemented.

The properties of the tool were as follows:
1. measuring and displaying values of the metrics for business process models in BPMN (initial functionality of the tool),
2. assessing the quality of business process models in BPMN based on the developed MAQ (functionality added after the MAQ was developed).

Currently in the field of modelling a variety of tools that contain implementation of some metrics exists. For example, in the context of BPMN, a tool called BPMN Quality has been created and it can measure a set of metrics chosen from the literature by its authors (Makni et al., 2010). However, to the best knowledge of the author of the thesis there is no tool, which basing on quality criteria will help to detect if measured values of metrics are good for a BPMN models or not. What is more, no tool was found that help to assess the level of fulfilment of the quality of sub-characteristics of BPMN models. Later, the tool may be also supplemented with new features or may be useful in other future research.

Therefore, the tool is available online and can be found in: <https://sourceforge.net/projects/bpmn-quality/>.

### 6.3 Initial functionality of the tool

#### 6.3.1 Verifying basic problems of the syntactic correctness

The sub-characteristic for Correctness, Syntactic correctness, is checked for each BPMN model using the following approaches:
1. a built-in syntax checker in Business Process Visual ARCHITECT v4.0\(^{14}\)
2. additional syntax checks in the plug-in which has been built-in to some of the more sensitive metrics.

The existing tool which checks the syntax is built-in Business Process Visual ARCHITECT v4.0. This functionality has been implemented so that the software helps analysts to concentrate on the design, because it provides feedback about whether the diagrams follow the BPMN 2.0 rules. The tool is described by the producer as BPMN-compliant and supports the most up-to-date BPMN standards\(^{15}\). Figure 6.1 shows the example of the problem detected by the tool while the BPMN model was being created.

---
\(^{14}\) The website of the producer: http://www.visual-paradigm.com
\(^{15}\) http://www.visual-paradigm.com/product/lz/reasons/
However, in Business Process Visual ARCHITECT (version 4.0, which was available to the author of the thesis), the built-in syntax checker had limited capabilities. It is possible and easy to design models in the tool which are not syntactically correct according to BPMN 2.0 specification (BPMN, 2011). This was beneficial for this thesis, because could allow BPMN models to be redrawn for the repository while preserving their original mistakes. However, it was also the reason why some additional basic syntaxes checks were built into the plug-in for some more sensitive metrics, e.g. the CC metric. Although it could be expected that this would be a part of the initial functionality of the software, the contrary is reality. What can be observed though is that the built-in syntax checker has limitations.

One example of a limitation of the tool is that it does not properly recognize some elements. For example, the linked intermediate event (with an arrow marker that has a black-colour fill) can have only incoming sequence flows. However, in the tool it is possible to create an outgoing sequence flow of such an event. The tool in some cases only provides warnings, and enables the user to produce BPMN models which violate the syntactic rules. One example of this situation can occur when connecting Tasks with Message Flows, which is incorrect. These are just a two of many examples of the limitation of the syntactic checker built-in to the tool.

Additionally, in a tool it is easy to create BPMN models that have some typical anty-patterns and even no warning is given to the user while saving the model. List of typical anty-patterns for BPMN models is summarized by (Rozman, Polancic & Horvat, 2007). Some examples are: not connected activities in one pool, process does not contain a start event, sequence flow crosses pool boundary or hanging intermediate events or activities.

6.3.2 “Quality Metrics” option

“Quality Metrics” option (see Figure 6.2) was created in order to measure and display values of the metrics selected in the Section 5 for business process models in BPMN. Two examples of results of this function are available:

– on Figure 6.3 (example in which all metrics could be calculated), and
– on Figure 6.4 (example in which not all metrics could be calculated).
Figure 6.2. “Quality Metrics” option available in menu or in toolbar.

Figure 6.3. Example 1 of calculations using “Quality Metrics” option.
6.3.3 “Show Relationship of Element” option

Popup menu with “Show Relationship of Element” option is an additional functionality of the plug-in. This functionality after implementation, helped a lot to the author of the thesis because it made it easy to get information about relationships of elements in more complex BPMN models or in BPMN models with bad aesthetics, e.g. where arches crosses. The analysis of the relationships of elements is also a base for almost every metric of the BPMN model (see Section 5).

“Show Relationship of Element” option lists all relationships of the chosen element from the BPMN model. Especially it provides information about:

− type of flow going to or from the chosen element, it distinguishes between sequence flow and message flow,
− name of the flow (if the flow has a name, “unnamed” otherwise),
− direction:
  − “To” – if the flow goes to the chosen element,
  − “From” – if the flow goes from the chosen element,
− icon of the BPMN model’s element to or from which the flow goes.

Next figures show examples of results of the application of the “Show Relationship of Element” option to different BPMN model’s elements:

− Figure 6.5 and Figure 6.6 show resulting relationships of the chosen gateway element,
− Figure 6.7 show resulting relationships of the chosen task element,
− Figure 6.8 show resulting relationships of the chosen sequence flow element,
- Figure 6.9 show resulting relationships of chosen task element that is not connected to other elements,
- Figure 6.10 show resulting relationships of the pool element.

![Figure 6.5. Popup menu with “Show Relationships of Element” option.](image)

![Figure 6.6. Resulting relationships of the AND gateway element (from the Figure 6.5).](image)
Figure 6.7 Resulting relationships of the C task element.

Figure 6.8. Resulting relationships of the sequence flow element.

Figure 6.9. Resulting relationships of task element not connected to other elements.

Figure 6.10. Resulting relationships of the Bank pool element.
6.4 Functionality added to the tool after the MAQ is developed

The “Quality Assessment” functionality of the tool was implemented when the MAQ was developed completely (see Section 9). In more detail, it was when there was knowledge on the quality criteria (see Section 7) and the quality functions (Section 8). “Quality Assessment” option (see Figure 6.11) shows the quality of model’s sub-characteristics and overall model’s quality (see example in Figure 6.12).

![Figure 6.11. “Quality Assessment” option available in menu or in toolbar.](image)

![Figure 6.12. Example of the results of “Quality Assessment” for a BPMN models.](image)
7 QUALITY CRITERIA

7.1 Introduction

Quality criteria are functions that appraise the quality of the metric results. A criteria can be defined as, “standards, rules, or tests on which a judgment or decision can be based, or by which a product, service, result, or process can be evaluated” (PMBOK, 2004). In this thesis, the quality criteria will be used to standardize the results of metrics. This will enable the evaluation of the metric’s results. Using the evaluation, the MAQ model (via the plug-in) will be able to indicate whether the quality is of a good or bad level for the specific metric.

This section will provide the answer for (RQ2.3): “How to interpret the values of the chosen metrics?”. A problem faced by the author of the thesis was that no metric (see Section 5) clearly defined when its values are good or bad. However, basic criteria were specified as to whether the metric’s result should be high or low. Because the goal of the author of the thesis was to propose a quality model for business process models in BPMN, quality criteria needed to be defined in a meaningful way. This meant that the criteria needed to indicate quality and be able to be used in the quality model. The Quality Criteria presented in this section are instances of Quality Criteria from metamodel described in Section 3.4 (see Figure 7.1). Grey classes are not presented in this section.

![Figure 7.1. Resulting elements of the MAQ model are based on the introduced metamodel (see also Figure 3.2).](image)

Firstly, the author of the thesis created Quality Rating (QR). This was the result of the need of the author to make a meaningful comparison of the results of quality metrics as part of the quality model. In order for the measurements to be meaningful, they need to remain relevant when statements are made about the level of quality (Briand, El Emam & Morasca, 1996). As a result, the author of the thesis defined Quality Rating (QR) as an ordinal scale that described whether the result of the metric was of good or bad quality on a scale of Class A (highest) through Class E (lowest).
The scale chosen was ordinal since the quantitative levels of quality had varying distance between them for each metric. For example, the range of values obtained from the BPMN repository for CP metric had a range of 0 to 0.3 and the CFC metric had a range from 0 to 16. Clearly, the ranges between metrics were different in practice and not easily comparable without the use of an ordinal scale.

The ordinal scale was created using BPMN models from the repository (see Section 6.1). The values for each entity of the ordinal scale were based on an interval of values which were relevant to each metric. For example, the CFC metric had an observed range from 0 to 16. In order to assign a reasonable interval for the highest elements, the author of the thesis used what the papers suggested as good or bad values. For example, in the case of the CFC metric the value should be low in order to attain a good quality. Clusterization of the metric was then used to create intervals of ordinal elements, e.g. zero to one for Class A and from one to four for Class B.

Quality criteria for metrics presented in this section are based on the results obtained from the literature and from measuring BPMN models from the repository and analysing them statistically. In order to achieve this aim, statistical software was used, i.e. Weka software\textsuperscript{16}. In more detail, Weka contains tools for clustering, from which simple k-means function was selected. The algorithm of k-means clustering is described in detail by Hartigan and Wong (1979).

In the k-means clustering function, the \( k \) value was declared as equal 4 or 2, based on the results of metrics used on the repository. Additionally, the author of the thesis chose seed values for each metric separately as follows:

\[
\text{seed} = (\text{Integer without rounding}) \times \frac{\text{maximal metric's value} - \text{minimal metric's value}}{2}
\]

In the following chapter, the results of defining quality criteria in terms of \( \text{QR} \) are shown in the form of tables. More specifically, in Section 9 the same quality criteria are presented in the form of equations.

### 7.2 Quality criteria for metrics

#### 7.2.1 Quality criteria for Coupling (CP) metric by Cardoso, Vanderfeesten and Reijers (2010)

Following Cardoso, Vanderfeesten and Reijers (2010), desired is low coupling CP value. Higher CP values are obtained by BPMN models which are more difficult to change, more likely to have defects and less easy to understand.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Real from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.2 and Appendix D):</td>
<td>([0.0, 0.333333])</td>
</tr>
</tbody>
</table>

\textbf{Table 7.1.} Summary of the CP metric.

Cardoso, Vanderfeesten and Reijers (2010) summarized that SAP models have a very low level of coupling with a mean of 0.0914. The mean value of the BPMN repository is also low and equals: 0.099446.

The author of the thesis propose Quality Criteria (see Table 7.2) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cluster1</td>
<td>0.176786</td>
</tr>
<tr>
<td>cluster0</td>
<td>0.114167</td>
</tr>
<tr>
<td>cluster2</td>
<td>0.064361</td>
</tr>
<tr>
<td>cluster3</td>
<td>0.003934</td>
</tr>
</tbody>
</table>

**Weka software settings:**
- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 0
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for CP metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.0, 0.003934)</td>
<td>Class A</td>
</tr>
<tr>
<td>[0.003934, 0.064361)</td>
<td>Class B</td>
</tr>
<tr>
<td>[0.064361, 0.114167)</td>
<td>Class C</td>
</tr>
<tr>
<td>[0.114167, 0.176786)</td>
<td>Class D</td>
</tr>
<tr>
<td>[0.176786, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

*Figure 7.2.* Result of measures of CP metric on the repository of BPMN models.
7.2.2 Quality criteria for Control-flow Complexity (CFC) metric by Cardoso (2005)

Following Cardoso (2005), desired is low complexity CFC value. Higher CFC values are obtained by BPMN models which are more complex, what indicates difficulties with their understanding by stakeholders. They are also more difficult to change.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.3 and Appendix D):</td>
<td>[0, 16]</td>
</tr>
</tbody>
</table>

Table 7.3. Summarison of the CFC metric.

![Figure 7.3](image)

Figure 7.3. Result of measures of CFC metric on the repository of BPMN models.

The author of the thesis propose Quality Criteria (see Table 7.4) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- cluster1 0.894737
- cluster0 3.529412
- cluster3 6.200000
- cluster2 11.333333

Weka software settings:
- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 8
- Maximum number of iterations: 500
Quality Criteria for CFC metric

<table>
<thead>
<tr>
<th>Quality Criteria for CFC metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0, 1)</td>
<td>Class A</td>
</tr>
<tr>
<td>[1, 4)</td>
<td>Class B</td>
</tr>
<tr>
<td>[4, 6)</td>
<td>Class C</td>
</tr>
<tr>
<td>[6, 11)</td>
<td>Class D</td>
</tr>
<tr>
<td>[11, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.4. Quality Criteria for the CFC metric.

7.2.3 Quality criteria for Cross-connectivity (CC) metric by Vanderfeesten et al. (2008)

Following Vanderfeesten et al. (2008), desired is high complexity CC value. Lower CC values are obtained by BPMN models which are more difficult to understand by stakeholders. They are also more likely to include errors.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Real from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.4 and Appendix D):</td>
<td>[0.0, 0.5]</td>
</tr>
</tbody>
</table>

Table 7.5. Summarison of the CC metric.

Figure 7.4. Result of measures of CC metric on the repository of BPMN models.

Simple k-means function is sensitive on very outstanding values. Therefore one value: 0.5 is removed from the set of results of measures. The author of the thesis propose Quality Criteria (see Table 7.6) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- cluster2: 0.007996
- cluster3: 0.030407
- cluster0: 0.061814
cluster 1 0.112903

Weka software settings:
- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 0
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for CC metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0, 0.007996)</td>
<td>Class E</td>
</tr>
<tr>
<td>[0.007996, 0.030407)</td>
<td>Class D</td>
</tr>
<tr>
<td>[0.030407, 0.061814)</td>
<td>Class C</td>
</tr>
<tr>
<td>[0.061814, 0.112903)</td>
<td>Class B</td>
</tr>
<tr>
<td>[0.112903, ∞)</td>
<td>Class A</td>
</tr>
</tbody>
</table>

Table 7.6. Quality Criteria for the CC metric.

7.2.4 Quality criteria for Imported Coupling of a Process (ICP) metric by Khlif et al. (2009)

Following Khlif et al. (2009), desired is low ICP value. Higher ICP values are obtained by BPMN models that have processes more depended on services offered by other processes. They should be avoided at least treated with special attention because they are more difficult change or maintain. Additionally, high ICP value may show increased error probability.

<table>
<thead>
<tr>
<th>Type of measurement method</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale</td>
<td>Integer from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.5 and Appendix D):</td>
<td>[0, 4]</td>
</tr>
</tbody>
</table>

Table 7.7. Summarison of the ICP metric.

![Figure 7.5. Result of measures of ICP metric on the repository of BPMN models.](image-url)
The author of the thesis propose Quality Criteria (see Table 7.8) that will determine the division on Quality Rating, basing on 2 clusters obtained through the use of the Weka software and two additional border values proposed by the author. The border values were added because it seems to be reasonable for the ICP metric, that bigger values may appear, despite the fact that the values obtained by the repository vary between 0 and 4.

| cluster0  | 0.967742 |
| cluster1  | 2.192308 |
| border_value1 | 4 |
| border_value2 | 10 |

Weka software settings:

- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 2
- Seed: 2
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for ICP metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0, 1)</td>
<td>Class A</td>
</tr>
<tr>
<td>[1, 2)</td>
<td>Class B</td>
</tr>
<tr>
<td>[2, 4)</td>
<td>Class C</td>
</tr>
<tr>
<td>[4, 10)</td>
<td>Class D</td>
</tr>
<tr>
<td>[10, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.8. Quality Criteria for the ICP metric.

7.2.5 Quality criteria for Exported Coupling of a Process (ECP) metric by Khlif et al. (2009)

Following Khlif et al. (2009), desired is low ECP value. Higher EPC values are obtained by BPMN models which have processes that provide service to many other processes. They should be avoided at least treated with special attention because they are more difficult change or maintain. Additionally, high ECP value may show increased error probability.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from zero to infinity</td>
</tr>
</tbody>
</table>

Scale obtained by measured BPMN models (see Figure 7.6 and Appendix D):

[0, 4]

Table 7.9. Summarison of the ECP metric.
Figure 7.6. Result of measures of ECP metric on the repository of BPMN models.

The author of the thesis propose Quality Criteria (see Table 7.10) that will determine the division on Quality Rating, basing on 2 clusters obtained through the use of the Weka software and two additional border values proposed by the author. The border values were added because it seems to be reasonable for the ECP metric, that bigger values may appear, despite the fact that the values obtained by the repository vary between 0 and 4.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 0</td>
<td>1.468085</td>
</tr>
<tr>
<td>Cluster 1</td>
<td>3.300000</td>
</tr>
</tbody>
</table>

**Quality Criteria for ECP metric**

<table>
<thead>
<tr>
<th>Value Range</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.3</td>
<td>Class A</td>
</tr>
<tr>
<td>3.3-5.3</td>
<td>Class B</td>
</tr>
<tr>
<td>5.3-10.0</td>
<td>Class C</td>
</tr>
<tr>
<td>10.0-</td>
<td>Class D</td>
</tr>
</tbody>
</table>

Table 7.10. Quality Criteria for the ECP metric.

7.2.6 Quality criteria for Cognitive Complexity Measure (W) by Gruhn and Laue (2006a)

Following Gruhn and Laue (2006a), desired is low cognitive weight (W) value. Higher W values are obtained by BPMN models which are more difficult to understand and change.
<table>
<thead>
<tr>
<th>Type of measurement method</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Integer from two to infinity (BPMN model with less than two nodes make no sense)</td>
</tr>
</tbody>
</table>

Scale obtained by measured BPMN models (see Figure 7.7 and Appendix D):

[2, 124]

Table 7.11. Summary of the W metric.

![Figure 7.7. Result of measures of W metric on the repository of BPMN models.](image)

The author of the thesis propose Quality Criteria (see Table 7.12) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

<table>
<thead>
<tr>
<th>cluster1</th>
<th>11.050000</th>
</tr>
</thead>
<tbody>
<tr>
<td>cluster0</td>
<td>19.526316</td>
</tr>
<tr>
<td>cluster2</td>
<td>32.200000</td>
</tr>
<tr>
<td>cluster3</td>
<td>98.333333</td>
</tr>
</tbody>
</table>

Weka software settings:

Simple k-means function
Implementing Euclidean distance (or similarity) function
Number of clusters: 4
Seed: 62
Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for W metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2, 11)</td>
<td>Class A</td>
</tr>
<tr>
<td>[11, 20)</td>
<td>Class B</td>
</tr>
<tr>
<td>[20, 32)</td>
<td>Class C</td>
</tr>
<tr>
<td>[32, 98)</td>
<td>Class D</td>
</tr>
<tr>
<td>[98, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.12. Quality Criteria for the W metric.
7.2.7 Quality criteria for Fan-in/Fan-out (FIO) metric by Gruhn and Laue (2006b)

Following Gruhn and Laue (2006b), desired is low (FIO) value. Higher structural complexity FIO values are obtained by BPMN models which are more difficult to comprehend and more likely to be badly designed.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.8 and Appendix D):</td>
<td>[0, 16]</td>
</tr>
</tbody>
</table>

Table 7.13. Summarison of the FIO metric.

![Figure 7.8](image-url) Result of measures of FIO metric on the repository of BPMN models.

The author of the thesis propose Quality Criteria (see Table 7.14) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- **cluster0**: 0
- **cluster1**: 1.4
- **cluster3**: 9
- **cluster2**: 16

Weka software settings:

- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 8
- Maximum number of iterations: 500
<table>
<thead>
<tr>
<th>Quality Criteria for FIO metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Class A</td>
</tr>
<tr>
<td>1</td>
<td>Class B</td>
</tr>
<tr>
<td>(1, 9)</td>
<td>Class C</td>
</tr>
<tr>
<td>[9, 16)</td>
<td>Class D</td>
</tr>
<tr>
<td>[16, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.14. Quality Criteria for the FIO metric.

7.2.8 Quality criteria for NOAJS and NOA metrics by Cardoso et al. (2006)

NOAJS and NOA metrics, in the opinion of the author of the thesis are quite different than other metrics discussed in this paper. As aforementioned in Section 5.5.7, the metrics were criticized because they consider only length aspect of BPMN models. However, they are very simple and they may be also very useful as indicators of BPMN models that are badly designed with an excessive number of activities. Additionally, they may give some information about BPMN model's understandability.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from one to infinity (BPMN model with less than one not event node make no sense)</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.9 and Appendix D):</td>
<td>[1, 27]</td>
</tr>
</tbody>
</table>

Table 7.15. Summarision of the NOA metric.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from one to infinity (BPMN model with less than one not event node make no sense)</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.10 and Appendix D):</td>
<td>[2, 37]</td>
</tr>
</tbody>
</table>

Table 7.16. Summarision of the NOAJS metric.
Figure 7.9. Result of measures of NOA metric on the repository of BPMN models.

Figure 7.10. Result of measures of NOAJS metric on the repository of BPMN models.

The author of the thesis propose Quality Criteria (see Table 7.17 and Table 7.18) that will determine the division on Quality Rating, basing on guidelines available from the literature:

Mendling, Reijers and van der Aalst (2010) proposed a set of seven process modeling guidelines (see Section 4.5.10), one guideline says:

G7 – Decompose a model with more than 50 elements.

However, BPMN model’s elements are not only activities or gateways but also e.g. events. Therefore, the author of the thesis thinks that as a border value a smaller value should be taken, e.g. 35.
Other guideline is given by Pitschke (2010): business process model must be limited in size and on the management perspective should contain no more than 25 business activities. In BPMN, an activity can be atomic (known as a Task) or compound (called Sub-Process). And in NOA and NOAJS metrics both kinds of activities are calculated together.

<table>
<thead>
<tr>
<th>Quality Criteria for NOA metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1, 25)</td>
<td>Class A</td>
</tr>
<tr>
<td>[25, 35)</td>
<td>Class D</td>
</tr>
<tr>
<td>[35, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.17. Quality Criteria for the NOA metric.

The author of the thesis could not find guidelines for number of gateway elements. However, BPMN model with no more than 5 gateway elements seems to be easy to understand. Therefore the author of the thesis added 5 to quality criteria borders for NOAJS metric.

<table>
<thead>
<tr>
<th>Quality Criteria for NOAJS metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1, 30)</td>
<td>Class A</td>
</tr>
<tr>
<td>[30, 35)</td>
<td>Class D</td>
</tr>
<tr>
<td>[35, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.18. Quality Criteria for the NOAJS metric.

7.2.9 Quality criteria for Process Difficulty (HPC_D) metric by Cardoso et al. (2006)

Following Cardoso et al. (2006), desired is low (HPC_D) value. Higher HPC_D values are obtained by BPMN models which are more difficult to maintain. Additionally, high HPC_D value may show increased error probability.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Real from more than zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.11 and Appendix D):</td>
<td>[0.833333, 8.750000]</td>
</tr>
</tbody>
</table>

Table 7.19. Summary of the HPC_D metric.
The author of the thesis propose Quality Criteria (see Table 7.20) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cluster0</td>
<td>1.369963</td>
</tr>
<tr>
<td>cluster1</td>
<td>2.316667</td>
</tr>
<tr>
<td>cluster2</td>
<td>4.300000</td>
</tr>
<tr>
<td>cluster3</td>
<td>8.625000</td>
</tr>
</tbody>
</table>

*Weka software settings:*

- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 3
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for HPC_D metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0, 1.369963)</td>
<td>Class A</td>
</tr>
<tr>
<td>[1.369963, 2.316667)</td>
<td>Class B</td>
</tr>
<tr>
<td>[2.316667, 4.300000)</td>
<td>Class C</td>
</tr>
<tr>
<td>[4.300000, 8.625000)</td>
<td>Class D</td>
</tr>
<tr>
<td>[8.625000, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

*Table 7.20. Quality Criteria for the HPC_D metric.*

7.2.10 Quality criteria for Process Length (HPC_N) metric by Cardoso et al. (2006)

Following Cardoso et al. (2006), desired is low (HPC_N) value. Higher HPC_N values are obtained by BPMN models which are more difficult to maintain. Additionally, high HPC_N value may show increased error probability.
Type of measurement method: Objective
Theoretically possible scale: Real from more than zero to infinity
Scale obtained by measured BPMN models (see Figure 7.12 and Appendix D): [4.754888, 240.855491]

<table>
<thead>
<tr>
<th>Scale obtained by measured BPMN models</th>
<th>[4.754888, 240.855491]</th>
</tr>
</thead>
</table>

Table 7.21. Summary of the HPC_N metric.

![Figure 7.12](image-url) Result of measures of HPC_N metric on the repository of BPMN models.

The author of the thesis propose Quality Criteria (see Table 7.22) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

| cluster1 | 11.500499 |
| cluster2 | 37.997488 |
| cluster3 | 93.197803 |
| cluster0 | 211.190200 |

Weka software settings:
- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 118
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for HPC_N metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0, 11.500499)</td>
<td>Class A</td>
</tr>
<tr>
<td>[11.500499, 37.997488)</td>
<td>Class B</td>
</tr>
<tr>
<td>[37.997488, 93.197803)</td>
<td>Class C</td>
</tr>
<tr>
<td>[93.197803, 211.190200)</td>
<td>Class D</td>
</tr>
<tr>
<td>[211.190200, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.22. Quality Criteria for the HPC_N metric.
7.2.11 Quality criteria for Process Volume (HPC_V) metric by Cardoso et al. (2006)

Following Cardoso et al. (2006), desired is low (HPC_V) value. Higher HPC_V values are obtained by BPMN models which are more difficult to maintain. Additionally, high HPC_V value may show increased error probability.

<table>
<thead>
<tr>
<th>Type of measurement method</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Real from more than zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.13 and Appendix D):</td>
<td>[1.0, 23,774438]</td>
</tr>
</tbody>
</table>

Table 7.23. Summarization of the HPC_V metric.

![Figure 7.13. Result of measures of HPC_V metric on the repository of BPMN models.](image)

The author of the thesis propose Quality Criteria (see Table 7.24) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- **cluster0**: 3.5980651
- **cluster1**: 7.2780990
- **cluster2**: 12.284659
- **cluster3**: 21.679919

Weka software settings:

- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 11
- Maximum number of iterations: 500
### Quality Criteria for HPC_V metric

<table>
<thead>
<tr>
<th>Quality Criteria for HPC_V metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0, 3.5980651)</td>
<td>Class A</td>
</tr>
<tr>
<td>[3.5980651, 7.2780990)</td>
<td>Class B</td>
</tr>
<tr>
<td>[7.2780990, 12.284659)</td>
<td>Class C</td>
</tr>
<tr>
<td>[12.284659, 21.679919)</td>
<td>Class D</td>
</tr>
<tr>
<td>[21.679919, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

**Table 7.24.** Quality Criteria for the HPC_V metric.

#### 7.2.12 Quality criteria for Interface Complexity of an Activity (IC) metric by Cargoso *et al.* (2006)

Desired is low IC complexity value. Higher values means that BPMN model is more difficult to understand.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from zero to infinity</td>
</tr>
</tbody>
</table>

| Scale obtained by measured BPMN models (see Figure 7.14 and Appendix D): | [0, 184] |

**Table 7.25.** Summarison of the IC metric.

**Figure 7.14.** Result of measures of IC metric on the repository of BPMN models.

Simple k-means function is sensitive on very outstanding values. Therefore two values: 142 and 184 are removed from the set of results of measures. The author of the thesis propose Quality Criteria (see Table 7.26) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- **cluster1**: 4.761905
- **cluster2**: 12.611111
- **cluster3**: 31.100000
- **cluster0**: 66.833333

**cluster4**: 66.833333
Weka software settings:

Simple k-means function
Implementing Euclidean distance (or similarity) function
Number of clusters: 4
Seed: 92
Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for IC metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0, 5)</td>
<td>Class A</td>
</tr>
<tr>
<td>[5, 13)</td>
<td>Class B</td>
</tr>
<tr>
<td>[13, 31)</td>
<td>Class C</td>
</tr>
<tr>
<td>[31, 67)</td>
<td>Class D</td>
</tr>
<tr>
<td>[67, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.26. Quality Criteria for the IC metric.

7.2.13 Quality criteria for Number of Nodes (Sn(G)) metric by Mendling (2008)

Following Mendling (2008), desired is low value of Sn(G) metric. Higher Sn(G) values are obtained by BPMN models which are more likely to have errors and more difficult to understand.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Integer from two to infinity (BPMN model with less than two nodes make no sense)</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.15 and Appendix D):</td>
<td>[2, 37]</td>
</tr>
</tbody>
</table>

Table 7.27. Summary of the Sn(G) metric.

Figure 7.15. Result of measures of Sn(G) metric on the repository of BPMN models.
The author of the thesis propose Quality Criteria (see Table 7.28) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- cluster3: 4.136362
- cluster1: 9.269231
- cluster2: 17.666667
- cluster0: 34.666667

Weka software settings:
- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 17
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for Sn(G) metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2, 4)</td>
<td>Class A</td>
</tr>
<tr>
<td>[4, 9)</td>
<td>Class B</td>
</tr>
<tr>
<td>[9, 18)</td>
<td>Class C</td>
</tr>
<tr>
<td>[18, 35)</td>
<td>Class D</td>
</tr>
<tr>
<td>(35, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.28. Quality Criteria for the Sn(G) metric.

7.2.14 Quality criteria for Coefficient of Connectivity (CNC(G)) metric by Mendling (2008)

Following Mendling (2008), desired is low value of CNC(G) metric. Higher CNC(G) values are obtained by BPMN modes which are more likely to have errors. Additionally, CNC(G) metric is useful to assess understandability and changeability and following Cargoso et al. (2006) in formal aesthetics the CNC(G) coefficient is considered with the notion of elegance.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Real from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.16 and Appendix D):</td>
<td>[0.0, 3.0]</td>
</tr>
</tbody>
</table>

Table 7.29. Summary of the CNC(G) metric.
The author of the thesis propose Quality Criteria (see Table 7.30) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

| cluster0 | 0.222222 |
| cluster2 | 1.338157 |
| cluster3 | 1.651778 |
| cluster1 | 2.266667 |

Weka software settings:

- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 4
- Seed: 1
- Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for CNC(G) metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.0, 0.222222)</td>
<td>Class A</td>
</tr>
<tr>
<td>[0.222222, 1.338157)</td>
<td>Class B</td>
</tr>
<tr>
<td>[1.338157, 1.651778)</td>
<td>Class C</td>
</tr>
<tr>
<td>[1.651778, 2.266667)</td>
<td>Class D</td>
</tr>
<tr>
<td>[2.266667, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.30. Quality Criteria for the CNC(G) metric.

7.2.15 Quality criteria for Sequentiality (S(G)) metric by Mendling (2008)

Following Mendling (2008), desired is high value of S(G) metric. Higher S(G) values are obtained by BPMN models which are less likely to have errors and easier to understand or modify.
Type of measurement method: | Objective
---|---
Theoretically possible scale: | Real from zero to one
Scale obtained by measured BPMN models (see Figure 7.17 and Appendix D): | [0.0, 1.0]

Table 7.31. Summarison of the S(G) metric.

![Figure 7.17. Result of measures of S(G) metric on the repository of BPMN models.](image)

The author of the thesis propose Quality Criteria (see Table 7.32) that will determine the division on Quality Rating, basing on 2 clusters obtained through the use of the Weka software and two additional border values proposed by the author of the thesis. The border values were added because it seems to be reasonable for the S(G) metric, that values between [0.553273 and 1.0) may appear more often, despite the fact that only 3 values in this set were obtained by the repository. The results of the division on 4 clusters using Weka software seemed for the author of the thesis unrealistically high.

| cluster0 | 0.107650 |
| cluster1 | 0.553273 |
| border_value1 | 0.750000 |
| border_value2 | 0.900000 |

Weka software settings:
- Simple k-means function
- Implementing Euclidean distance (or similarity) function
- Number of clusters: 2
- Seed: 0
- Maximum number of iterations: 500
Quality Criteria for S(G) metric

<table>
<thead>
<tr>
<th>Quality Criteria for S(G) metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.0, 0.107650)</td>
<td>Class A</td>
</tr>
<tr>
<td>[0.107650, 0.553273)</td>
<td>Class B</td>
</tr>
<tr>
<td>[0.553273, 0.750000)</td>
<td>Class C</td>
</tr>
<tr>
<td>[0.750000, 0.900000)</td>
<td>Class D</td>
</tr>
<tr>
<td>[0.900000, 1.0]</td>
<td>Class E</td>
</tr>
</tbody>
</table>

Table 7.32. Quality Criteria for the S(G) metric.

7.2.16 Quality criteria for Density (d(G)) metric by Mendling (2008)

Following Mendling (2008), desired is low value of d(G) metric. Higher d(G) values are obtained by BPMN models which are more likely to have errors or are more difficult to modify.

<table>
<thead>
<tr>
<th>Type of measurement method:</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretically possible scale:</td>
<td>Real from zero to infinity</td>
</tr>
<tr>
<td>Scale obtained by measured BPMN models (see Figure 7.18 and Appendix D):</td>
<td>[0.0, 3.0]</td>
</tr>
</tbody>
</table>

Table 7.33. Summarison of the d(G) metric.

![Figure 7.18](image)  
Figure 7.18. Result of measures of d(G) metric on the repository of BPMN models.

The author of the thesis propose Quality Criteria (see Table 7.34) that will determine the division on Quality Rating, basing on 4 clusters obtained through the use of the Weka software:

- cluster2: 0.136169
- cluster0: 0.357143
- cluster3: 0.741667
- cluster1: 2.333333
**Weka software settings:**

Simple k-means function
Implementing Euclidean distance (or similarity) function
Number of clusters: 4
Seed: 1
Maximum number of iterations: 500

<table>
<thead>
<tr>
<th>Quality Criteria for d(G) metric</th>
<th>Quality Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.0, 0.136169)</td>
<td>Class A</td>
</tr>
<tr>
<td>[0.136169, 0.357143)</td>
<td>Class B</td>
</tr>
<tr>
<td>[0.357143, 0.741667)</td>
<td>Class C</td>
</tr>
<tr>
<td>[0.741667, 2.333333)</td>
<td>Class D</td>
</tr>
<tr>
<td>[2.333333, ∞)</td>
<td>Class E</td>
</tr>
</tbody>
</table>

**Table 7.34.** Quality Criteria for the d(G) metric.
8 Quality Functions

8.1 Introduction

In this section the quality functions for MAQ are introduced. Quality functions (QF) are functions that combine the result of quality criteria of the sub-characteristics. This provides the answer to (RQ2.4): “How to evaluate the quality of characteristics?”. The Quality Functions presented in this section are instances of Quality Functions from metamodel described in Section 3.4 (see Figure 8.1). Grey classes are not presented in this section.

More specifically, the result of the QF results in a Quality Rating (QR) for each BPMN model. The QR is a scale that is used for the result of both quality criteria and quality functions. An example of a sub-characteristic, its corresponding metrics, and the results of the quality criteria is provided in Figure 8.2.

Figure 8.1. Resulting elements of the MAQ model are based on the introduced metamodel (see also Figure 3.2).

Figure 8.2. Interpretation of the quality functions.
There are many possible interpretations for how to propose quality functions. For example, the quality function for a sub-characteristic can be calculated as follow:

- The worst Quality Rating obtained by the metrics is assigned to the sub-characteristic
  \[ Q_{\text{F, sub-characteristic}} = \max \{ QR \} \]
  e.g.1: for BPMN model A from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class C} \)
  e.g.2: for BPMN model B from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class C} \)

- The best Quality Rating obtained by the metrics is assigned to the sub-characteristic
  \[ Q_{\text{F, sub-characteristic}} = \min \{ QR \} \]
  e.g.1: for BPMN model A from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class A} \)
  e.g.2: for BPMN model B from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class B} \)

- The ceiling of the mean Quality Rating obtained by the metrics assigned to the sub-characteristic
  Let Class A=1, Class B=2, Class C=3, Class D=4, Class E=5
  \[ Q_{\text{F, sub-characteristic}} = (QR) \left[ \sum_{m=1}^{M} QR_m \right] / M \]
  e.g.1: for BPMN model A from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class B} \)
  e.g.2: for BPMN model B from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class C} \)

- The floor of the mean Quality Rating obtained by the metrics assigned to the sub-characteristic
  Let Class A=1, Class B=2, Class C=3, Class D=4, Class E=5
  \[ Q_{\text{F, sub-characteristic}} = (QR) \left[ \sum_{m=1}^{M} QR_m \right] / M \]
  e.g.1: for BPMN model A from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class B} \)
  e.g.2: for BPMN model B from Figure 8.1: \( Q_{\text{F, sub-characteristic}} = \text{Class B} \)

- etc.

In this section, the author of the thesis proposes another possible interpretation of the results. The interpretation uses the Fibonacci sequence. The Fibonacci sequence has been used in planning poker (Molökken-Ostvold & Haugen, 2007), and helps in estimating the differences in sizes of work items. It is relevant since the first four numbers are prime and prevent the thinking that direct comparisons can be made between values. This is applicable to the scale of quality since the distance between QR varies depending on the quality criteria. The QR should not be compared as ratios of each other, i.e. Class D is half the quality of Class E would be incorrect. As a result of using the Fibonacci sequence, the author of the thesis avoids these comparisons since the first four numbers are prime and are not ratios of each other.

Furthermore, when the quality is bad, it is important that this is clear to the user. The Fibonacci sequence increases rapidly from the initial value of 1 to 8. As a result, the QR for bad quality can be represented using higher values such as 8 in order to make the quality function more sensitive to bad quality.

Nevertheless, at this stage of research in the field it is difficult to assess if this interpretation is acceptable. Further research should investigate which interpretation of quality function is best for combining metrics for models in BPMN.
8.2 Quality functions for quality sub-characteristics

Let’s assign numeric values to Quality Rating starting from the third value of the Fibonacci sequence:

\[
PoinA(metric) = \begin{cases} 
1, & \text{if } QC(metric, BPMN model) = \text{Class A} \\
2, & \text{if } QC(metric, BPMN model) = \text{Class B} \\
3, & \text{if } QC(metric, BPMN model) = \text{Class C} \\
5, & \text{if } QC(metric, BPMN model) = \text{Class D} \\
8, & \text{if } QC(metric, BPMN model) = \text{Class E} 
\end{cases}
\]

Quality function for quality sub-characteristics will be defined as follows:

\[
Q_{sch}^{def} \equiv (\text{Lower QR}) \left[ \frac{\sum_{m=1}^{M_1} PoinA(\text{metricOK}_m) + \sum_{m=1}^{M_2} PoinA(\text{metricUndefined}_m)}{M_1 + M_2} \right]
\]

where

- \text{metricOK} – metric that can be calculated for every BPMN model
- \text{metricUndefined} – metric that can produce undefined value (when BPMN model cannot be calculated)
- \(M_1\) – number of metrics classified to \text{metricOK} group
- \(M_2\) – number of metrics classified to \text{metricUndefined} group, which produced non-undefined values for the measured BPMN model.
- \text{Lower QR} – the result of the equation is then transferred into the adequate Quality Rating.

In the case of getting a value that cannot be easily interpret, the lower (worse) value of Quality Rating will be assigned. For example, the results of quality criteria with the assigned values are: Class A = 1, Class C = 3, Class E = 8. This results in:

\[
(Lower QR) \left[ \frac{1 + 3 + 8}{3} \right] = (Lower QR)[4] = \text{Class D}
\]

The above interpretation of the quality function was adopted because:

- Not every metric can be calculated for each BPMN model (hence the need for differentiation between \text{metricOK} and \text{metricUndefined}, see Table 8.1).
- The \text{metricUndefined} metrics that give undefined values should be excluded from the calculation of sub-characteristics. Only \text{metricUndefined} metric results which result in a non-undefined result should be used in the equation.
- The Fibonacci sequence and ceiling function were chosen because in the opinion of the author of the thesis, it is more informative to have results that are sensitive to low quality. Additionally in order to make the QR more sensitive to bad quality, the Fibonacci sequence is used starting from the third value. These more sensitive results show clearly when the quality is low.

<table>
<thead>
<tr>
<th>Sub-characteristic</th>
<th>List of \text{metricOK} group of metrics</th>
<th>List of \text{metricUndefined} group of metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changeability</td>
<td>CFC, ICP, ECP, W</td>
<td>S_G, CP</td>
</tr>
<tr>
<td>Reusability and extensibility</td>
<td>FIO</td>
<td>none</td>
</tr>
<tr>
<td>Minimality and simplicity</td>
<td>NOAJS, NOA, FIO</td>
<td>none</td>
</tr>
</tbody>
</table>
8.3 Quality function for the whole model

The overall model’s quality is based on the quality functions for the sub-characteristics and the results gathered from the survey. The details of the survey are presented in Section 10 and the survey is included in Appendix D. One question from the survey is analysed here and it provides knowledge that is needed. That is, the priorities that should be assigned to quality sub-characteristics (Question A). The results from this question are used to propose the quality function for the whole MAQ model.

Question A: Please rate the importance of the following quality characteristics for BPMN models. (5 – very important)

For analysing this question the survey responses of only Expert respondents were used. Expert responses were the only ones used since they can be considered to have the greatest knowledge of BPMN. According to the opinion of the Expert respondents (see Figure 8.3), the two quality characteristics of “Understandability” and “Correctness” were more important than others. The author of the thesis also share this opinion, because:

- the BPMN models should adhere to the rules of the BPMN notation in order to be correct, i.e. syntax, style rules, naming conventions (Syntactic correctness, because Semantic correctness cannot be assessed automatically by the tool, see Section 4.6.2),
- a BPMN model is not useful if is not easily understandable (Understandability).

<table>
<thead>
<tr>
<th>Correctness</th>
<th>Integrity</th>
<th>Modifiability</th>
<th>Complexity</th>
<th>Understandability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average ranges (Experts)</td>
<td>4.6</td>
<td>3.5</td>
<td>3.9</td>
<td>3.1</td>
</tr>
<tr>
<td>Rounded values (Experts)</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 8.2. Priorities for characteristics proposed by the Expert respondents.
The priorities that will be used in the MAQ model for sub-characteristics are based on the rounded values of average ranges proposed by the Experts. Furthermore, the quality function for MAQ model is based on the weighted arithmetic mean of quality functions for sub-characteristics.

\[
\text{Fun} = 5 \cdot \text{PointB}(\text{QF}_{\text{sc}}) + 4 \cdot \text{PointB}(\text{QF}_{\text{ch}}) + 4 \cdot \text{PointB}(\text{QF}_{\text{re}}) + 3 \cdot \text{PointB}(\text{QF}_{\text{ms}})
+ 5 \cdot \text{PointB}(\text{QF}_{\text{uc}}) + 5 \cdot \text{PointB}(\text{QF}_{\text{am}})
\]

Quality function for overall MAQ model will be defined as follows:

\[
\text{QF}_{\text{model}} = \frac{\text{Fun}}{5 + 4 + 4 + 4 + 5 + 5} = \left(\text{Lower QR}\right)\left\lceil \frac{\text{Fun}}{27} \right\rceil
\]

where

- \(\text{QF}_{\text{sc}}\) – quality function for Syntactic correctness
- \(\text{QF}_{\text{ch}}\) – quality function for Changeability
- \(\text{QF}_{\text{re}}\) – quality function for Reusability and extensibility
- \(\text{QF}_{\text{ms}}\) – quality function for Minimality and simplicity
- \(\text{QF}_{\text{uc}}\) – quality function for User comprehensibility
- \(\text{QF}_{\text{am}}\) – quality function for Aesthetics of model

\(\text{Lower QR}\) – the result of the equation is then transferred into the adequate Quality Rating.

In the case of getting a value that cannot be easily interpret, the lower (worse) value of Quality Rating will be assigned.
9  MODEL FOR ASSESSING THE QUALITY OF BUSINESS PROCESS MODELS IN BPMN

This section summarises developed model for assessing the quality of business process models in BPMN (MAQ). MAQ model is an instance of the metamodel presented in the Section 3.4 and Figure 3.2.

Figure 9.1 shows three aspects of MAQ model. These are: quality characteristics, quality sub-characteristics and quality metrics. Other two aspects of the MAQ model – quality criteria and quality functions were developed in Sections 7 and 8 and are summarized below.

![Diagram of MAQ model]

Figure 9.1. MAQ – quality characteristics, quality sub-characteristics and quality metrics.
Figure 9.2. MAQ – quality sub-characteristic: Syntactic Correctness.
Figure 9.3. MAQ – quality sub-characteristic: Changeability.

Figure 9.4. MAQ – quality sub-characteristic: Reusability and extensibility.

Figure 9.5. MAQ – quality sub-characteristic: Minimality and simplicity.
Figure 9.6. MAQ – quality sub-characteristic: User comprehensibility.

Figure 9.7. MAQ – quality sub-characteristic: Aesthetics of models.
The summary of the quality criteria:

For CP metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{CP}_{\text{metric}}(\text{BPMN model}) \in [0.0, 0.003934) \\
\text{Class B, if } \text{CP}_{\text{metric}}(\text{BPMN model}) \in [0.003934, 0.064361) \\
\text{Class C, if } \text{CP}_{\text{metric}}(\text{BPMN model}) \in [0.064361, 0.114167) \\
\text{Class D, if } \text{CP}_{\text{metric}}(\text{BPMN model}) \in [0.114167, 0.176786) \\
\text{Class E, if } \text{CP}_{\text{metric}}(\text{BPMN model}) \in [0.176786, \infty) 
\end{cases}
\]

For CFC metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{CFC}_{\text{metric}}(\text{BPMN model}) \in [0, 1) \\
\text{Class B, if } \text{CFC}_{\text{metric}}(\text{BPMN model}) \in [1, 4) \\
\text{Class C, if } \text{CFC}_{\text{metric}}(\text{BPMN model}) \in [4, 6) \\
\text{Class D, if } \text{CFC}_{\text{metric}}(\text{BPMN model}) \in [6, 11) \\
\text{Class E, if } \text{CFC}_{\text{metric}}(\text{BPMN model}) \in [11, \infty) 
\end{cases}
\]

For CC metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{CC}_{\text{metric}}(\text{BPMN model}) \in [0.112903, \infty) \\
\text{Class B, if } \text{CC}_{\text{metric}}(\text{BPMN model}) \in [0.061814, 0.112903) \\
\text{Class C, if } \text{CC}_{\text{metric}}(\text{BPMN model}) \in [0.030407, 0.061814) \\
\text{Class D, if } \text{CC}_{\text{metric}}(\text{BPMN model}) \in [0.007996, 0.030407) \\
\text{Class E, if } \text{CC}_{\text{metric}}(\text{BPMN model}) \in [0, 0.007996) 
\end{cases}
\]

For ICP metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{ICP}_{\text{metric}}(\text{BPMN model}) \in [0, 1) \\
\text{Class B, if } \text{ICP}_{\text{metric}}(\text{BPMN model}) \in [1, 2) \\
\text{Class C, if } \text{ICP}_{\text{metric}}(\text{BPMN model}) \in [2, 4) \\
\text{Class D, if } \text{ICP}_{\text{metric}}(\text{BPMN model}) \in [4, 10) \\
\text{Class E, if } \text{ICP}_{\text{metric}}(\text{BPMN model}) \in [10, \infty) 
\end{cases}
\]

For ECP metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{ECP}_{\text{metric}}(\text{BPMN model}) = 0 \\
\text{Class B, if } \text{ECP}_{\text{metric}}(\text{BPMN model}) \in [1, 3) \\
\text{Class C, if } \text{ECP}_{\text{metric}}(\text{BPMN model}) \in [3, 5) \\
\text{Class D, if } \text{ECP}_{\text{metric}}(\text{BPMN model}) \in [5, 10) \\
\text{Class E, if } \text{ECP}_{\text{metric}}(\text{BPMN model}) \in [10, \infty) 
\end{cases}
\]

For W metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{W}_{\text{metric}}(\text{BPMN model}) \in [2, 11) \\
\text{Class B, if } \text{W}_{\text{metric}}(\text{BPMN model}) \in [11, 19) \\
\text{Class C, if } \text{W}_{\text{metric}}(\text{BPMN model}) \in [19, 32) \\
\text{Class D, if } \text{W}_{\text{metric}}(\text{BPMN model}) \in [32, 98) \\
\text{Class E, if } \text{W}_{\text{metric}}(\text{BPMN model}) \in [98, \infty) 
\end{cases}
\]

For FIO metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{FIO}_{\text{metric}}(\text{BPMN model}) = 0 \\
\text{Class B, if } \text{FIO}_{\text{metric}}(\text{BPMN model}) = 1 \\
\text{Class C, if } \text{FIO}_{\text{metric}}(\text{BPMN model}) \in [2, 9) \\
\text{Class D, if } \text{FIO}_{\text{metric}}(\text{BPMN model}) \in [9, 16) \\
\text{Class E, if } \text{FIO}_{\text{metric}}(\text{BPMN model}) \in [16, \infty) 
\end{cases}
\]

For NOA metric:

\[
QC_{\text{BPMN}} = \begin{cases} 
\text{Class A, if } \text{NOA}_{\text{metric}}(\text{BPMN model}) \in [1, 25) \\
\text{Class D, if } \text{NOA}_{\text{metric}}(\text{BPMN model}) \in [25, 35) \\
\text{Class E, if } \text{NOA}_{\text{metric}}(\text{BPMN model}) \in [35, \infty) 
\end{cases}
\]
For NOAJS metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{NOAJS\_metric(BPMN\_model)} \in [1, 30) \\
\text{Class D, if } \text{NOAJS\_metric(BPMN\_model)} \in [30, 35) \\
\text{Class E, if } \text{NOAJS\_metric(BPMN\_model)} \in [35, \infty)
\end{cases}
\]

For HPC\_D metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{HPC\_D\_metric(BPMN\_model)} \in (0, 1.369963) \\
\text{Class B, if } \text{HPC\_D\_metric(BPMN\_model)} \in [1.369963, 2.316667) \\
\text{Class C, if } \text{HPC\_D\_metric(BPMN\_model)} \in [2.316667, 4.3) \\
\text{Class D, if } \text{HPC\_D\_metric(BPMN\_model)} \in [4.3, 8.625) \\
\text{Class E, if } \text{HPC\_D\_metric(BPMN\_model)} \in [8.625, \infty)
\end{cases}
\]

For HPC\_N metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{HPC\_N\_metric(BPMN\_model)} \in (0, 11.500499) \\
\text{Class B, if } \text{HPC\_N\_metric(BPMN\_model)} \in [11.500499, 37.997488) \\
\text{Class C, if } \text{HPC\_N\_metric(BPMN\_model)} \in [37.997488, 93.197803) \\
\text{Class D, if } \text{HPC\_N\_metric(BPMN\_model)} \in [93.197803, 211.1902) \\
\text{Class E, if } \text{HPC\_N\_metric(BPMN\_model)} \in [211.1902, \infty)
\end{cases}
\]

For HPC\_V metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{HPC\_V\_metric(BPMN\_model)} \in (0, 3.5980651) \\
\text{Class B, if } \text{HPC\_V\_metric(BPMN\_model)} \in [3.5980651, 7.278099) \\
\text{Class C, if } \text{HPC\_V\_metric(BPMN\_model)} \in [7.278099, 12.284659) \\
\text{Class D, if } \text{HPC\_V\_metric(BPMN\_model)} \in [12.284659, 21.679919) \\
\text{Class E, if } \text{HPC\_V\_metric(BPMN\_model)} \in [21.679919, \infty)
\end{cases}
\]

For IC metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{IC\_metric(BPMN\_model)} \in [0, 5) \\
\text{Class B, if } \text{IC\_metric(BPMN\_model)} \in [5, 13) \\
\text{Class C, if } \text{IC\_metric(BPMN\_model)} \in [13, 31) \\
\text{Class D, if } \text{IC\_metric(BPMN\_model)} \in [31, 67) \\
\text{Class E, if } \text{IC\_metric(BPMN\_model)} \in [67, \infty)
\end{cases}
\]

For Sn\_G metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{Sn\_G\_metric(BPMN\_model)} \in [2, 4) \\
\text{Class B, if } \text{Sn\_G\_metric(BPMN\_model)} \in [4, 9) \\
\text{Class C, if } \text{Sn\_G\_metric(BPMN\_model)} \in [9, 18) \\
\text{Class D, if } \text{Sn\_G\_metric(BPMN\_model)} \in [18, 35) \\
\text{Class E, if } \text{Sn\_G\_metric(BPMN\_model)} \in [35, \infty)
\end{cases}
\]

For CNC\_G metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{CNC\_G\_metric(BPMN\_model)} \in [0.0, 0.222222) \\
\text{Class B, if } \text{CNC\_G\_metric(BPMN\_model)} \in [0.222222, 1.338157) \\
\text{Class C, if } \text{CNC\_G\_metric(BPMN\_model)} \in [1.338157, 1.651778) \\
\text{Class D, if } \text{CNC\_G\_metric(BPMN\_model)} \in [1.651778, 2.266667) \\
\text{Class E, if } \text{CNC\_G\_metric(BPMN\_model)} \in [2.266667, \infty)
\end{cases}
\]

For S\_G metric:
\[
\text{QC(BPMN\_model)} = \begin{cases} 
\text{Class A, if } \text{S\_G\_metric(BPMN\_model)} \in [0.0, 0.10765) \\
\text{Class B, if } \text{S\_G\_metric(BPMN\_model)} \in [0.10765, 0.553273) \\
\text{Class C, if } \text{S\_G\_metric(BPMN\_model)} \in [0.553273, 0.75) \\
\text{Class D, if } \text{S\_G\_metric(BPMN\_model)} \in [0.75, 0.9) \\
\text{Class E, if } \text{S\_G\_metric(BPMN\_model)} \in [0.9, 1.0]
\end{cases}
\]
For $d_G$ metric:

\[
QC(BPMN\text{-model}) = \begin{cases} 
\text{Class A, if } d_G\text{-metric}(BPMN\text{-model}) \in [0.0, 0.136169) \\
\text{Class B, if } d_G\text{-metric}(BPMN\text{-model}) \in [0.136169, 0.357143) \\
\text{Class C, if } d_G\text{-metric}(BPMN\text{-model}) \in [0.357143, 0.741667) \\
\text{Class D, if } d_G\text{-metric}(BPMN\text{-model}) \in [0.741667, 2.333333) \\
\text{Class E, if } d_G\text{-metric}(BPMN\text{-model}) \in [2.333333, \infty) 
\end{cases}
\]

The summary of the quality functions:

**Quality function for quality sub-characteristics:**

\[
QF_{sch} \overset{\text{def}}{=} \left(\text{Lower } QR\right) \left[ \frac{\sum_{m=1}^{M_1} \text{PointA(metricOk}_m) + \sum_{m=1}^{M_2} \text{PointA(metricUndefined}_m)}{M_1 + M_2} \right]
\]

where

\[
\text{PointA(metric)} = \begin{cases} 
1, & \text{if } QC(\text{metric, BPMN model}) = \text{Class A} \\
2, & \text{if } QC(\text{metric, BPMN model}) = \text{Class B} \\
3, & \text{if } QC(\text{metric, BPMN model}) = \text{Class C} \\
5, & \text{if } QC(\text{metric, BPMN model}) = \text{Class D} \\
8, & \text{if } QC(\text{metric, BPMN model}) = \text{Class E} 
\end{cases}
\]

*metricOk* – metric that can be calculated for every BPMN model

*metricUndefined* – metric that can produce undefined values (when BPMN model cannot be calculated)

$M_1$ – number of metrics classified to *metricOk* group

$M_2$ – number of metrics classified to *metricUndefined* group, which produced non-undefined values for the measured BPMN model.

**Lower QR** – the result of the equation is then transferred into the adequate Quality Rating.

In the case of getting a value that cannot be easily interpret, the lower (worse) value of Quality Rating will be assigned. For example, the results of quality criteria with the assigned values are: Class A = 1, Class C = 3, Class E = 8. This results in:

\[
(\text{Lower } QR) \left[ \frac{1+3+8}{3} \right] = (\text{Lower } QR)[4] = \text{Class D}
\]

(All explanations in the Section 8.2)

**Quality function for overall MAQ model:**

\[
QF_{\text{model}} \overset{\text{def}}{=} \left(\text{Lower } QR\right) \left[ \frac{\text{Fun}}{5+4+4+4+5+5} \right] = (\text{Lower } QR) \left[ \frac{\text{Fun}}{27} \right]
\]

\[
\text{Fun} = 5 \cdot \text{PointB}(QF_{sc}) + 4 \cdot \text{PointB}(QF_{ch}) + 4 \cdot \text{PointB}(QF_{re}) + 3 \cdot \text{PointB}(QF_{ms})
+ 5 \cdot \text{PointB}(QF_{uc}) + 5 \cdot \text{PointB}(QF_{am})
\]

where

\[
\text{PointB}(QF_{\text{char}}) = \begin{cases} 
1, & \text{if } QF_{\text{char}} = \text{Class A} \\
2, & \text{if } QF_{\text{char}} = \text{Class B} \\
3, & \text{if } QF_{\text{char}} = \text{Class C} \\
5, & \text{if } QF_{\text{char}} = \text{Class D} \\
8, & \text{if } QF_{\text{char}} = \text{Class E} 
\end{cases}
\]
QFsc – quality function for Syntactic correctness
QFch – quality function for Changeability
QFre – quality function for Reusability and extensibility
QFms – quality function for Minimality and simplicity
QFuc – quality function for User comprehensibility
QFam – quality function for Aesthetics of model

Lower QR – the result of the equation is then transferred into the adequate Quality Rating.

In the case of getting a value that cannot be easily interpret, the lower (worse) value of Quality Rating will be assigned.

(All explanations in the Section 8.3)
10 Evaluation of the MAQ Model Using Survey-Based Experiment

This section provides the answer to the (RQ3): “Is the developed model for assessing the quality of business process models in BPMN considered as useful?”. In order to answer this question, the author of the thesis conducted a survey (for attached survey see Appendix D). Later, the author of the thesis decided to conduct a second iteration of the survey, in order to get more responses from Expert group of respondents (see Table 10.1 and Table 10.2).

10.1 Survey study design

10.1.1 Reasons for the need for the survey

In reality the survey (see Appendix D) consists of three surveys which were sent together in order to ease the process of distribution and gathering results. Each of the surveys had different purpose and therefore can be distinguished from the other. The reasons why surveys were chosen in this study are as follows:

Survey 1: The first survey contained one question only. The author of the thesis needed to propose priorities for characteristics in order to calculate the overall model’s quality (for the results see Section 8.3). The results of the survey contributed to an understanding of the priorities of the identified quality characteristics and how important are different characteristics against each other based on their priorities.

Survey 2: The second survey was conducted in order to obtain data for the experiment (see Section 10.2). The purpose of the survey-based experiment was to check if the Expert respondent’s evaluation of the quality of BPMN models agreed with the results determined by the MAQ model. This indicated how useful the proposed MAQ model and the tool for the automatic assessment of the quality of business process models in BPMN were.

Survey 3: The third survey was conducted in order to investigate in retrospect what respondents think about the idea of the model for assessing the quality of business processes models in BPMN (MAQ) and the tool, which implements the model. Moreover, it was investigated if the MAQ model would be useful for the respondents.

10.1.2 Types of questions

The research was questionnaire-based and was provided to the respondents, who agreed to take part in the survey (population is described in Section 10.1.3). Both iterations of the survey were sent out in the form of an attachment using e-mail. In some surveys, respondents left additional comments. Some of them extended or added details to the survey’s questions. These additional responses which were added to the survey by respondents were later analysed in a qualitative manner.
The survey was based on the questionnaire which consisted of closed questions. Closed questions are when the respondents answer using a predefined set of answers. The closed scale was chosen, because it allows for a more quantitative feedback to the survey.

The research contained also the initial demographical questions. The demographically related questions asked about the respondent’s name, email and experience level with BPMN. It was needed to group answers based on the group of respondents - Experts, Learners and Novices (for more information see Section 10.1.3).

Before sending the survey the author of the thesis prepared an Excel spreadsheet\(^\text{17}\) which was used to analyse the results. In it, the tables for diagrams and statistics used were prepared before survey responses were collected.

### 10.1.3 Population

The survey population consisted of experts of BPMN as well as students, who were learning BPMN or were novices to BPMN but know other notations or methodologies used with business processes. The survey population was broken down into the following groups:

- **Experts** can be described as, respondents, who classify themselves as experts who have knowledge on BPMN or who are using BPMN in work, research or for private purposes.
- **Learners** can be defined as mostly students of Wrocław University of Technology (Poland), who have/had a course on BPMN. But also respondets who are learning BPMN.
- **Novices** were generally students of Blekinge Institute of Technology (Sweden) or Wrocław University of Technology (Poland), who do not know BPMN but who have knowledge of other notations or methodologies for business processes, for example UML Activity Diagram, UML EDOC Business Processes, IDEF, ebXML BPSS, Activity-Decision Flow (ADF) Diagram, RosettaNet, LOVEM, or Event-Process Chains (EPCs).

In **Survey 1** and **Survey 2** only answers from **Expert** respondents were taken into account. It is common knowledge that experts can provide more correct estimations of quality based on their knowledge of a domain area. Therefore the author of the thesis wanted only **Experts** to evaluate the MAQ model and only **Experts** to propose priorities for characteristics in order to calculate the overall model’s quality. In **Survey 3** all responses were analysed in order to provide feedback about the idea of the model for assessing the quality of business processes models in BPMN (MAQ) and the tool, which implements the model.

The population of the survey is presented in **Table 10.1**. During the first iteration of the survey 35 answers were collected. During the second iteration of the survey, 10 answers were collected. In total the author of the thesis obtained 45 answers (see **Table 10.2**).

<table>
<thead>
<tr>
<th>Num.</th>
<th>Name of group</th>
<th>Short description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Experts</td>
<td>Selected, “I am using BPMN in work, research, for private purposes, etc.” AND described the level of BPMN notation knowledge as ≥ 3.</td>
</tr>
<tr>
<td>2</td>
<td>Learners</td>
<td>Selected, “I have/had a course on BPMN. I am learning BPMN.” and not selected “I am using BPMN in work, research, for private purposes, etc.” OR selected, “I am using BPMN in work, research, for private purposes, etc.” AND described the level of BPMN notation knowledge as ≤ 2.</td>
</tr>
<tr>
<td>3</td>
<td>Novices</td>
<td>Selected, “I do not know BPMN but I have knowledge of other notations or methodologies for business processes, for example UML Activity Diagram, UML EDOC Business Processes, IDEF, ebXML BPSS, Activity-Decision Flow (ADF) Diagram, RosettaNet, LOVeM, or Event Process Chains (EPCs)”</td>
</tr>
</tbody>
</table>

Table 10.1. Population of the survey.

The survey represented a general population of BPMN Experts, Learners and Novices. In total there were 172 persons contacted about the survey. 125 of the people contacted were potential experts and 47 were students. The author of the thesis identified potential experts to be contacted, however the final classification if someone is an expert or not was based on results of the survey (See Table 10.2; 2 potential experts were classified as Learners not Experts based on the obtained results).

For the students only a snowballing approach was used whereby they were requested to share the survey with people who were learning about BPMN or had relevant knowledge. Snowball Sampling, “is a non-probability sampling technique that is used by researchers to identify potential subjects in studies where subjects are hard to locate” (Castillo, 2009). Students who knew of other people who would be relevant to the survey were able to share the survey with other students. There were two iterations of the survey that were conducted. The first iteration consisted of both students and potential experts, while the second iteration consisted of only potential experts.

For the first iteration 102 persons were contacted. Of those 102 persons, the group of persons contacted was broken down by students and experts. For the respective groups:

- 55 potential experts were contacted in the first iteration. From the Experts there were 8 responses, which resulted in a 15% expert response rate.
- 47 students were contacted. From the students there were 27 responses, which resulted in a response ratio of 57%. The high response ratio for students can be explained by the use of snowball sampling for the group.

In order to gather more expert responses a second iteration of directly contacting 70 potential experts was conducted. Of the 70 potential experts contacted 8 responded of which 6 were finally classified as Experts. This resulted in a response ratio of 9%. The author of the thesis believes the response ratio of 15% and 9% was reasonable.
### Table 10.2. Number of responses versus groups.

<table>
<thead>
<tr>
<th>Name of group</th>
<th>Number of respondents of the survey (first iteration)</th>
<th>Number of respondents of the survey (second iteration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts</td>
<td>8 respondents</td>
<td>6 respondents</td>
</tr>
<tr>
<td>Learners</td>
<td>8 respondents</td>
<td>2 respondents</td>
</tr>
<tr>
<td>Novices</td>
<td>19 respondents</td>
<td>none</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>35 respondents</strong></td>
<td><strong>Total:</strong> <strong>8 respondents</strong></td>
</tr>
</tbody>
</table>

In the next two sections, the gathered results are analysed from the viewpoint of the goals set for the paper.

## 10.2 Survey-Based Experiment

### 10.2.1 Objective and Design

The aim of the study was to evaluate practical usefulness of the MAQ model. This was done by comparing assessment given by MAQ model and assessment given by Expert respondents. It was checked if the respondent’s evaluation of the quality of BPMN models agreed with the results determined by the MAQ model. This indicated how useful the proposed MAQ model and the tool for the automatic assessment of the quality of business process models in BPMN were.

The Expert respondents assessed three BPMN models based on the sub-characteristics identified in the thesis. The sub-characteristics for each BPMN model were assessed using the previously introduced Quality Rating (QR) from Class A to Class E. The same process was done by the tool that implements the MAQ model (see Figure 10.1). Later, the result were compared and analysed.

![Figure 10.1](image.png)

**Figure 10.1.** Visualization of the design of the experiment.
The goal of this experiment is defined according to the goal template (Wohlin et al., 2012):

*Analyse the quality of BPMN models for the purpose of the evaluation of the MAQ model with respect to its accuracy in the evaluation of quality of business process models in BPMN from the point of view of BPMN Experts in the context of the business process modeling domain.*

The main question, which is to be answered in this experiment, is whether MAQ model evaluates the quality of BPMN models correctly and therefore is useful in practice.

This experiment is limited to examining business process models in BPMN and Process Diagrams only. The same limitation is applicable for the whole thesis.

### 10.2.2 Objects

The objects of the study are BPMN models. The models in BPMN are described in the Basic Concepts section (Section 2).

### 10.2.3 Independent and dependent variables

There are three models in BPMN which are the *independent variable of the experiment*. The BPMN models for the survey were chosen in order to be of either good or bad quality. The choice of the models was based on the author’s knowledge. However, the first two BPMN models were also clearly evaluated by the tool as being of good quality, while the final BPMN model was evaluated as being of low quality. The author of the thesis selected the evaluated BPMN models as relevant since they represented both good and bad quality models. Two BPMN models of good quality were chosen, because they were visually different even if they were both of good quality (they were also assessed by the tool as of good quality).

Besides quality, a number of other concerns were taken into consideration when selecting the BPMN models for the survey. Firstly, the models needed to be non-trivial by representing processes that could be of importance. For example, the three BPMN models represented, a trouble ticket system, a purchase ordering process and a software upgrade process. Secondly, the BPMN models needed to be complex, but not overly so in order for the person taking the survey to understand them. This is seen in the models as they do not consist of more than 50 elements (including flows). Thirdly, the number of BPMN models used was chosen to be three in order to increase the response rate of the survey (more models could discourage some of the respondents). All of these reasons contributed to the choice of three non-trivial and appropriately complex models.

The assessment by the tool that implement MAQ model and the assessment by Experts that responded the survey are two *dependent variables of the experiment*. Dependent variables of the experiment were selected in order to understand the correlation between the respondent’s ratings of the quality versus the tool’s using the Quality Rating (QR) scale.
10.2.4 Subjects

Only responses from Expert respondents were taken into account in the experiment. For detailed description of the subjects see Section 10.1.3.

10.2.5 Hypotheses

Null hypothesis

$H_0$: The mean of the survey result for each characteristic was equal to the MAQ model’s result. ($H_0$: $\mu_{\text{survey}} = MAQ_{\text{result}}$)

Alternative hypothesis

$H_1$: The mean of the survey result for each characteristic was not equal to the MAQ model’s result. ($H_1$: $\mu_{\text{survey}} \neq MAQ_{\text{result}}$)

The hypotheses were tested using a student’s t-test and the 95% confidence interval of the mean of the Expert responses.

1.2.6 Analysis

In order to understand if the result of the MAQ model represents the opinion of Experts with 95% confidence, the student’s t-test was used. This statistical analysis was done based on the hypotheses that if the result of the MAQ model (tool) fell within the confidence interval of the Expert’s opinion it would show that the tool is a feasible answer from a population of Experts.

The question in the survey was as follows:

**Question B:** Please rate the sub-characteristics using the ‘quality rank’ for the following BPMN models, based on your experience. (see Appendix E for evaluated BPMN models in the survey)

**Results of examining BPMN model A from the survey:**

The Expert’s mean survey results for Model A were between the range of 1 and 3. For the results of the Experts’ survey on BPMN model A, the sub-characteristic of Changeability and User comprehensibility fell within the 95% confidence interval.
Moreover, the mean of the Expert surveys showed a result very similar to the result of the tool for the User comprehensibility sub-characteristic. The majority of Experts gave the same quality assessment as the tool for the sub-characteristics: Changeability and Minimality and simplicity.

Figure 10.3. Bar graph comparing quality rank frequency for model A.

Figure 10.4. Expert’s survey results versus tool with AVG and 95% confidence interval for model A.

Results of examining BPMN model B from the survey:

The sub-characteristics of Syntactic correctness, Changeability, User comprehensibility and Aesthetics of the model were within the 95% confidence interval. MAQ model results which fell outside of the confidence interval, and were consequently rejected were Reusability and extensibility, and Minimality and simplicity. The majority of Experts gave the same quality assessment as the tool for the sub-characteristics: Changeability, User comprehensibility and Aesthetic of models. The distribution of Expert responses for sub-characteristics can be seen in Figure 10.5.
Results of examining BPMN model C from the survey:

The final BPMN model (model C), consisted of mixed results that ranged between high and low quality. Most quality sub-characteristics were given a QR of 5, which was of low quality. The quality of characteristics for BPMN model C, matched closely for User comprehensibility and Aesthetics of model between the majority of Expert respondents to the survey and the tool result. Of note is that the other sub-characteristics were close as well as seen from the distribution of values in Figure 10.7.

For the Expert survey responses the four sub-characteristics of Syntactic correctness, Changeability, User comprehensibility, and Aesthetics of the model were inside of the confidence interval. The Reusability and maintainability sub-characteristic measured by the MAQ model, was also in the confidence interval in the results of the Expert survey but to a lesser extent than the other four sub-characteristics. MAQ model result are not equal at a 95% confidence level. The most of the results of the MAQ model fall into the confidence interval of the Expert surveys and that the MAQ model more closely aligns with the mean of the Expert responses.
10.2.6 Conclusions

Overall, based on the results of the student’s t-test showing the 95% confidence interval of Experts versus the tools result, the tool provided answers that matched the confidence interval for the sub-characteristics of Changeability and User comprehensibility for all three models surveyed. This provides a strong indication that the tool produces results similar to the total population of Experts provided with 95% confidence for the sub-characteristics.

The results for the sub-characteristics of Syntactic correctness and Aesthetics of the model provide a strong indication in two of the three models that the tool is in agreement with the Experts using the student’s t-test. The lack of confidence in one of the models for each characteristic could be the result of the subjective nature of quality. For example, the difference between Class B, with a QR of 2; and Class C, with a QR of 3 is something that would be difficult subjectively to estimate. Given the subjective nature of quality, the MAQ model still provides a strong indication that it does not reject the results of Experts for the sub-characteristics of Syntactic correctness and Aesthetics of the model.
There was only one result of the tool which fell within the confidence interval for
the characteristic of Reusability and extensibility. As a result, when the t-test shows
that the result of the MAQ model falls outside of the 95% confidence interval,
it rejects the hypothesis that the mean of the survey and the MAQ model are equal for
the sub-characteristic.

There was none results of the tool which fell within the confidence interval for
the characteristic of Minimality and simplicity. As a result, when the t-test shows that the
result of the MAQ model falls outside of the 95% confidence interval, it
rejects the hypothesis that the mean of the survey and the MAQ model are equal for the
sub-characteristic.

The results can be presented in the following table:

<table>
<thead>
<tr>
<th>Sub-characteristic</th>
<th>Rejected in tested models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changeability, User comprehensibility</td>
<td>0 of 3 models</td>
</tr>
<tr>
<td>Syntactic correctness, Aesthetics of the model</td>
<td>1 of 3 models</td>
</tr>
<tr>
<td>Reusability and extensibility</td>
<td>2 of 3 models</td>
</tr>
<tr>
<td>Minimality and simplicity</td>
<td>3 of 3 models</td>
</tr>
</tbody>
</table>

Table 10.3. Results of the survey-based experiment.

In summary, the results of the student t-test give no reason to reject the hypothesis
that the mean of Expert’s surveyed for Changeability and User comprehensibility
is equal to the result of the MAQ model. Furthermore, there is an indication that for
the sub-characteristics of Syntactic correctness and Aesthetics of the model that the
mean of the Expert surveys being equal to the MAQ model is generally not rejected in
most cases. Finally, for Reusability and extensibility and Minimality and simplicity
most evidence from the survey indicates that the MAQ model’s equality to the Expert
survey result should be rejected.

10.3 Survey on usefulness of the MAQ model

The survey consisted of a number of questions that respondents were asked for the
opinion on the usefulness of MAQ model. It was conducted in order to investigate
in retrospect what respondents think about the idea of the model for assessing the
quality of business processes models in BPMN (MAQ) and the tool, which implements
the model.

Question C1: As a practitioner, would it be helpful for you to have a tool which
automatically assesses the quality of models made in BPMN? (see Figure 10.9)

Almost all Experts and Learners and the majority of Novices agreed that the idea
of having a tool for automatic assessment of the quality of models in BPMN is helpful.

Additionally, one Expert advised that the tool should also aid while designing
in order to disallow incorrect modeling. The other Expert left no answer and asked
“What would be a quality measure?” This thesis is aimed in answering this question and Section 9 gathers all findings for the MAQ model.

Figure 10.9. Responses to Question C1.

Question C2: Would you redesign your BPMN model if a tool that automatically access your BPMN model showed that it was of bad quality? (see Figure 10.10)

The answers showed that the majority of Experts and Learners would be willing to redesign the created BPMN model and trust the results of tool that automatically accesses the quality of BPMN models if the tool would show that the quality of the BPMN model is bad. Additionally, more Novices agreed than disagreed. One Novice respondent disagreed with redesigning BPMN model based on the tool’s assessment if the BPMN model would be used to develop software. The respondent argued that main factors that should influence the decision in this situation are the length of the support for the software and its size.

One Expert wrote that the decision should depend on the circumstances. The other Expert agreed that he might be willing to redesign BPMN model, however it would depend on the tool’s suggestions. One another Expert disagreed unless the tool would give good suggestions and the user could select a better alternative.

Figure 10.10. Responses to Question C2.

Question C3: Would you redesign your BPMN model if a tool for automatic assessment of the quality of business process models in BPMN showed that the model you created will not be understandable for all stakeholders? (see Figure 10.11)
As a result of answering the question, most of the respondents agreed that if a BPMN model would not be understandable for all stakeholders (based on the assessment provided by the tool), they would be willing to redesign the model.

The author of the thesis thinks that the two quality sub-characteristics: “User comprehensibility” and “Syntactic correctness” are more important than the others. A similar opinion was shared by the majority of the Expert and Learner respondents (see Section 8.3 and Question A). Additionally, models in BPMN should be readily understandable by all business users (see Section 2.3). This seems to be fulfilled by the notation because for example one Novice respondent of the survey wrote that he was not sure which of the provided BPMN models was syntactically correct however he understood the flow of models, except the last model, which in reality was syntactically incorrect.

![Figure 10.11. Responses to Question C3.](image)

**Question C4:** To what extent do you agree that the automatic assessment of the quality of business process models in BPMN can replace the analysis performed by the BPMN expert with domain knowledge. (see Figure 10.12)

Many of the respondents were not sure whether assessment of the quality of BPMN models could replace the analysis of a BPMN expert with domain knowledge.

From the perspective of Experts, a BPMN expert with domain knowledge is irreplaceable. For example, one Expert explained that the experience cannot be replaced by the tool, as the outcome might be syntactically correct BPMN model, but not what the user wanted to express. Similarly, the other Expert argued: “an automated quality check will not be able to adjust the errors, so human interaction cannot be bypassed or replaced”.

Many aspects of quality are difficult to assess without relevant domain knowledge such as Integrity or Semantic correctness. This is because, there are often context specific factors which are difficult to be automatically assesses in the business process models. Therefore, in the MAQ model these aspects also were not automatically calculated.
Results from Section 10.3 can be summarized as follows:

- Experts would find a tool that automatically assesses quality for BPMN helpful.
- Experts would be willing to redesign the model if shown that it was of bad quality by the tool.
- Experts would be willing to redesign the model if shown it was not understandable for all stakeholders by the tool.
- Experts disagreed that experts with domain knowledge were replaceable in assessing the quality of models.
11 LIMITATIONS AND THREATS TO VALIDITY

11.1 Limitations

A limitation of this thesis is that quality characteristics which cannot be measured automatically without having the necessary knowledge of the domain or other additional information beyond the model itself were not be taken into further consideration. Metrics were not assigned to them and they were not implemented (see Section 4.5).

The 57 business process models in BPMN collected from five different sources presents a sample of limited models. An effort was made to collect models of diverse quality and from different sources. The varying quality is apparent by the variance of results produced from the metrics used (see Section 7.2), which indicates that the models are indeed of varying quality.

In the survey, Learners and Novices were primarily from Blekinge Institute of Technology (Sweden) and Wrocław University of Technology (Poland). As a result, the survey results for Novices and Learners are limited to the population of these universities.

The conclusions regarding the accuracy of the tool and opinions of experts are based on fourteen Expert responses from 125 potential experts contacted. The Experts who have answered may not be representative of the complete BPMN expert population.

11.2 Threats to Validity

This thesis presents a number of threats to validity. The author of the thesis has identified the relevant threats to validity to explain them and their mitigating factors. Threats to validity for research in the field of software engineering are presented as consisting of four types, which are: construct validity, conclusion validity, internal validity and external validity (Wohlin et al., 2012). Firstly, conclusion validity threats are issues which affect the way conclusions are made from treatments, and are primarily concerned with the statistical significance of the conclusion. Secondly, threats to the internal validity are concerned with whether the relationship between the treatment and outcome is causal. This means that the relationship between the treatment and outcome cannot be caused by some unknown factor. Thirdly, construct validity is if the theory (i.e. cause and effect) and the observation (i.e. treatment and outcome) are related in a causal way. And fourthly, the external validity is concerned whether the result of the research is generalizable to a scope larger than the thesis itself. For each type of validity threat, the author of the thesis identified risks that could pose a threat to the validity of the thesis. The following threats were identified.

1) Conclusion validity

Reliability of measures: When measurements are not consistently applied it can create a risk that the validity is threatened. In the thesis, the author created a tool so that all metrics, quality criteria and quality functions were calculated automatically. This was done in order to mitigate the threat that measurements would be unreliable.
Treatment implementation: There is a risk when the treatment is not equally applied in a study. The author of the thesis applied treatments to BPMN models and survey participants. The author of the thesis mitigated this risk by creating an automated tool to test each model in a standard way. Moreover, the survey participants were given the same survey in English, or a Polish translation of the survey, in order to standardize the survey collection.

Random heterogeneity of BPMN models and respondents: Variation poses a risk when the objects under study are heterogeneous. The BPMN models in thesis needed to be heterogeneous in terms of quality since the author of the thesis was assessing good and bad quality. In order to mitigate the consequences of heterogeneous BPMN models, the author of the thesis narrowed the focus to specifically focus on Process Diagrams in BPMN notation. Furthermore, the respondents to the survey were heterogeneous in their experience levels with business process models in BPMN. This is a trade-off the author of the thesis has made in order to be able to better generalize the survey results to the general population.

2) Internal Validity

Selection of BPMN models: BPMN models were selected by the author of the thesis. The models were selected from publically available sources where the licensing allowed for them to be used for research. This poses a threat to validity since models which are licensed in a research-friendly way could be different than BPMN models in general. In order to mitigate this, the author of the thesis collected 57 models from 5 different sources in order to achieve a more general selection. Furthermore, the author of the thesis needed to redraw a number of models, so they could be used by the plug-in created by the author. The author of the thesis tried to rewrite the models without defects. However, rewriting the models could contain defects.

Selection of BPMN models in survey: There were three models chosen to be used in the survey. They were selected based on their varying quality in respect to the quality sub-characteristics measured. By selecting only three models of the 57 models there is a threat to validity that models were selected which are not representative of the whole population of business process models.

Selection of Experts: Naturally there is a variation in the level expertise in the field of BPMN, and so the experts contacted may not be representative of the whole BPMN expert population. The author of the thesis tried to mitigate this threat by contacting 125 experts directly and also verifying that they considered themselves to be experts through the survey (see Section 10.1.3).

3) Construct validity

Inadequate preoperational explication of quality criteria and functions: There is a threat to validity when the constructs used in the thesis are not well-defined enough before applying them as measurements. Constructs that are not well-defined can affect how effective the process is in achieving the outcomes of the thesis. The metrics which the quality criteria indicate quality for were previously unspecified in the literature. The author of the thesis has specified them using clusterization and created an ordinal scale. Furthermore, quality functions were defined in order to aggregate based on a defined process. Both the quality criteria and functions were
previously not defined, but the author of the thesis has proposed them in order to adequately conduct the thesis.

**Mono-method bias:** When a study uses only one method of measurement which biases the study it can lead to mono-method bias. For example, if productivity is measured only using lines of code it can produce a biased measurement since it is not always correct. All quality criteria were measured using the same ordinal scale from *Class A* to *Class E*. However, the underlying criteria for each element of the scale were different for corresponding metrics. While using a single Quality Rating (*QR*) scale to measure the metric result introduces a mono-method bias, the underlying metrics all have intervals which are individually defined. This reduces the threat that each model is being measured using the same method since every metric is measured in its own way before being used in the quality model.

**Lack of metric validation:** When the metrics used in the thesis have not been validated theoretically or empirically and used in the MAQ model it can pose a threat to the validity of the model. Some metrics were additionally adjusted to the BPMN notation by the author. In this thesis the author has identified the metrics which have been validated and which have not been individually in Section 5.5. Furthermore, the author of the thesis has only chosen metrics which come from scientific research and so the author of the thesis has based the selection on peer-reviewed metrics. Moreover, the results of the MAQ model, which use the metrics is evaluated against expert responses. Finally metrics have been identified specifically by the author of the thesis as a field of future research, which the author has provided the implementation and adaption for.

4) **External validity**

**Interaction of selection and treatment:** This is a threat when the subject of study is not representative of the general population. The author of the thesis selected quality characteristics using a SLR with a well-defined protocol that followed systematic guidelines (Kitchenham & Charters, 2007). Furthermore, the metrics were selected using a defined set of selection criteria that was applied to the selection criteria. As a result, the author of the thesis used a well-defined methodology in order to collect quality characteristics and metrics from the population of scientific literature relevant to BPMN model.

**Generalization of BPMN models:** Threats to validity as a result of BPMN models not being generalized to the population pose a risk since the result of the thesis can only be generalized to an appropriate scope. The BPMN models used in the thesis consist only of BPMN Process Diagrams. This means that the conclusions should not be generalized to Collaboration Diagrams or Choreography Diagrams. Furthermore, the author of the thesis collected 57 models of varying quality in order to achieve a population of models representative of the general business process model population.

**Generalization of survey responses:** There is a risk that the survey results are not generalizable to the practitioner population when the sample used is not representative. In the case of the thesis’ survey, the author of the thesis surveyed Experts from around the world. However, Learner and Novice responses primarily came from Blekinge Institute of Technology (Sweden) and Wrocław University of Technology (Poland). As a result, the results for novices and learners may not be representative of the population.
12 CONCLUSIONS AND FUTURE RESEARCH

12.1 Conclusions

This paper presents a model for quality assessment of models in BPMN (MAQ). By conducting the thesis, the goal was that practitioners would be able to evaluate the quality of their BPMN models using MAQ. In order to accomplish this, the author of the thesis first adopted ISO/IEC 1926 standard in a metamodel of models for assessing the quality of BPMN models (RQ1), and later developed a MAQ model (RQ2) and evaluated its usefulness (RQ3).

In order to be able to create a model of quality assessment of models in BPMN (MAQ) the author of the thesis checked what quality characteristics of models exist in the literature (RQ2.1) and chose relevant for BPMN (RQ2.1.1), found and adjusted suitable metrics (RQ2.2), proposed quality criteria (RQ2.3) and quality functions (RQ2.4). Finally, the proposed model of quality assessment of models in BPMN was implemented as a plug-in\(^{18}\) for Business Process Visual ARCHITECT v4.0 and evaluated for usefulness through a survey and survey-based experiment.

The characteristics Correctness, Integrity, Modifiability, Complexity and Understandability were extracted as relevant to BPMN models from the literature. Characteristics were further divided into sub-characteristics: Syntactic correctness, Semantic correctness, Informational completeness, Consistency, Accordance with purpose, Changeability, Reusability and extensibility, Minimality and simplicity, User comprehensibility and Aesthetics of model. Characteristics were grouped based on similarities resulting from a systematic literature review. The author of the thesis systematized and/or extended the quality characteristics relevant to business process models in BPMN.

In total seventeen metrics relevant to the identified characteristics were selected from the scientific literature and adapted for BPMN. The majority of the metrics chosen from the scientific literature needed to be adjusted and adapted in order to be used on real BPMN models. Some metrics were proposed, but only worked under specific conditions. These metrics were not useful on real BPMN models until the author of the thesis adapted or changed them. One example was the CP metric that was only proposed with XOR, OR and AND gateways. However, in order for the metric to work with real BPMN models, the author of the thesis needed to add assumptions to the metric in order to deal with other types of gateways. With the adaptions proposed and implemented as part of MAQ, the metrics and the plug-in implementing them will be able to be also used in future research.

Quality criteria (QC) were proposed based on analysis the results of measurements of the BPMN repository using implemented plug-in and k-means clustering function from WEKA software. The clusterization used results of measurements of a repository of models of varying quality. For results of measurements see Appendix D.

The result of the survey on the usefulness of model for quality assessment of models in BPMN showed that it was useful. For example, if the plug-in indicated to the practitioner that quality was low, they would make changes in the diagram. In practice,

\(^{18}\) Plug-in is available online: http://sourceforge.net/projects/bpmn-quality/.
this means that practitioners would be willing to use the plug-in in order to improve the quality of their models. The survey results were inconclusive whether an automated tool (plug-in) could replace the analysis of an expert in the domain.

In the survey-based experiment, the equality of the mean of expert’s assessment of the quality of the surveyed BPMN models with that of the plug-in was mostly not rejected. This was tested using the result of the plug-in and the mean of Expert responses based on a 95% confidence interval using the student’s t-test. Specifically, the results of the MAQ model fell within the confidence interval for the characteristics of Changeability and User comprehensibility for all three models indicating that the equality of Expert’s responses and the tool’s responses cannot be rejected for the models surveyed. The hypothesis of Expert and tool agreement was rejected in only one of the three models for the sub-characteristics of Syntactic correctness and Aesthetics of the model. Finally, Reusability and extensibility was rejected in two of the three models and Minimality and simplicity was rejected in all models, indicating that they mostly did not equal the response of Experts.

MAQ only indicates quality. It is not an absolute measure. It should be used to understand when quality could be bad or good. However, as the survey indicated, expert or domain knowledge related to a specific diagram is important.

### 12.2 Future research

While working on the model for assessing the quality of business process models in BPMN, the author of the thesis found the following areas for future research.

The author of the thesis built the model for assessing the quality of business process models in BPMN (MAQ) for BPMN Process Diagrams only. Future research can develop models for assessing the quality of Collaboration Diagrams and Choreography Diagrams in BPMN. As far as quality characteristics, MAQ may be the same for models for assessing the quality of Collaboration Diagrams or Choreography Diagrams, the metrics and therefore the quality criteria and quality functions should be different than in MAQ. Additionally, currently very little research is conducted in the field of metrics that could be directly applicable for BPMN Collaboration or Choreography Diagrams.

Some of the quality metrics from the literature could be more concretized that the author proposed. Further concretization would involve additional research. For example for the:

- **Coupling (CP) metric** (Cardoso, Vanderfeesten & Reijers, 2010) – It is not known what value should be used for gateway-gateway connections. Moreover, the value of arcs going from \( t_1 \) to \( t_2 \) connected elements in situations where \( t_1 \rightarrow \text{gateway} \rightarrow t_2 \) and the type of gateway is other than AND, OR, XOR is not known.

- **Control-flow Complexity metric** (CFC) (Cardoso, 2005) – The value for BPMN models with types of gateways other than AND, OR, XOR is not known.

- **Cross-connectivity (CC) metric** (Vanderfeesten et al., 2008) – It is not known what value BPMN models should have that contain events and how events influence the results. Moreover, the value of BPMN models with gateways other than AND, OR, XOR is not known.
Interface Complexity (IC) of an activity metric (Cargoso et al., 2006). It is not clear how length value should be calculated for BPMN models. Consequently, the author made assumptions for tasks and sub-processes, however future research may propose better values.

Future research could also propose more metrics that can measure the Reusability and extensibility sub-characteristic especially if no sub-processes are a part of the BPMN model. The only metric assigned by the author of the thesis for this sub-characteristic is proposed by Gruhn and Laue (2006b) and takes into consideration only sub-processes in BPMN.

Additionally, not all of the metrics chosen from the literature were validated. Also, the author of the thesis made changes in some of the metrics found in literature, which have not yet been validated. Future research could validate these proposed metrics.

The tool that implemented the model for assessing the quality of business process models in BPMN (MAQ) could be extended with additional functionality. For example, the tool could assist the design of BPMN models by disallowing low quality modeling or provide suggestions or propose alternatives for how to redesign a BPMN model which is of bad quality.
REFERENCES


APPENDIX A – RESULTS OF THE SYSTEMATIC LITERATURE REVIEW


APPENDIX B – EVIDENCE OF (SUB-)CHARACTERISTICS BASED ON THE LITERATURE

1) Some names of the characteristics may be misleading because the same name of the characteristic in the literature was chosen by different authors to describe different aspects of modes. Therefore the author of the thesis suggests not to pay great attention on names, but to refer to the appropriate sections to see the full description of the characteristic.

2) Sometimes the same characteristic from the literature was chosen by the author of the thesis as the relevant description for two or more sub-characteristics. This situation mostly appeared when description from the literature was very general.

3) Only characteristics relevant to BPMN were listed below and other characteristics were omitted. Similarly, too general characteristics from the literature were omitted.

4) When sub-characteristics were gathered in tables below, the author of the thesis named characteristics and assigned similar sub-characteristics to characteristics based on similarities of concepts.

1) Sub-characteristics for Correctness: Syntactic correctness:

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<td>Quality framework by Lindland, Sindre and Sølvberg (1994)</td>
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<td>4.1.2</td>
<td>Syntax quality</td>
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</tr>
<tr>
<td>4.1.3</td>
<td>C1-Correctness</td>
<td>6C goals by Mohaghegh, Dehlen and Neple (2009)</td>
</tr>
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<td>4.1.5</td>
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<td>The Perceived Quality of the End Products (PQEP) by Ssebuggwawo, Hoppenbrouwers and Proper (2010)</td>
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<tr>
<td>4.1.7</td>
<td>Syntactic quality</td>
<td>SIQ framework for process models by Mendling, Reijers and van der Aalst (2010)</td>
</tr>
<tr>
<td>4.1.8</td>
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<tr>
<td>4.1.11</td>
<td>syntax</td>
<td>Quality aspects by Unhelkar (2005)</td>
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2) Sub-characteristics for Correctness: *Semantic correctness*

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<td>Semantic quality: Validity and Completeness</td>
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<td>4.1.8</td>
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3) Sub-characteristics for Integrity: *Informational completeness*

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<td>A taxonomy of model quality aspects by Arendt and Taentzer (2010)</td>
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5) Sub-characteristics for Integrity: *Accordance with purpose*

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6) Sub-characteristics for Modifiability: *Changeability*

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<td>A taxonomy of model quality aspects by Arendt and Taentzer (2010)</td>
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7) Sub-characteristics for Modifiability: *Reusability and extensibility*

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8) Sub-characteristics for Complexity: *Minimality and Simplicity*

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<td>G7 – Decompose a model with</td>
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more than 50 elements by Mendling, Reijers and van der Aalst (2010)

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9) Sub-characteristics for Understandability: *User comprehensibility*

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10) Sub-characteristics for Understandability: *Aesthetics of diagrams*

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## APPENDIX C – MODEL DETAILS FROM THE REPOSITORY OF BPMN MODELS

Source numbers (identifiers), model numbers (identifiers), names and formats of the original models in BPMN:

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<th>Model number</th>
<th>Name and format of the original model</th>
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<td>R1</td>
<td>triso - Hardware Retailer v2.bpmn</td>
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<td>S1</td>
<td>R2</td>
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<td>Examples - DI - Expanded Sub-Process.vsd</td>
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<td>R7</td>
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APPENDIX E – SURVEY

Name and surname: _____________________________________
E-mail: ______________________________________________

☐ I have/had a course on BPMN. I am learning BPMN.
☐ I am using BPMN in work, research, for private purposes, etc.
☐ I do not know BPMN but I have knowledge of other notations or methodologies for business processes, for example UML Activity Diagram, UML EDOC Business Processes, IDEF, ebXML BPSS, Activity-Decision Flow (ADF) Diagram, RosettaNet, LOVeM, or Event-Process Chains (EPCs).

Please select a number which best describes the level of your knowledge of BPMN notation:

Scale:
1. I am a novice of BPMN. 2. 3. 4. 5. I am an expert of BPMN.

Part 1: Evaluation of the model for assessing the quality of business process models in BPMN

1. As a practitioner, would it be helpful for you to have a tool which automatically assesses the quality of models made in BPMN?
   a) Yes.
   b) No.

2. Would you redesign your BPMN model if a tool that automatically accessed your BPMN model showed that it was of bad quality?
   a) Yes.
   b) No.

3. Would you redesign your BPMN model if a tool for automatic assessment of the quality of business process models in BPMN showed that the model you created will not be understandable for all stakeholders?
   a) Yes.
   b) No.

4. To what extend do you agree that the automatic assessment of the quality of business process models in BPMN can replace the analysis performed by the BPMN expert with domain knowledge.
   ▪ I strongly agree
   ▪ I agree
   ▪ I am not sure
   ▪ I disagree
   ▪ I strongly disagree

5. Please rate the importance of the following quality characteristics for BPMN models. (5 – very important)
   ▪ Correctness 1 2 3 4 5
   ▪ Integrity 1 2 3 4 5
   ▪ Modifiability 1 2 3 4 5
   ▪ Complexity 1 2 3 4 5
   ▪ Understandability 1 2 3 4 5
Part 2: Evaluation of the practical use of the model for assessing the quality of business process models in BPMN

Please rate the sub-characteristics using the ‘classes of quality’ for the following BPMN models, based on your experience.

**Class A** – the sub-characteristic, treated separately from others, has a **high quality**

**Class E** – the sub-characteristic, treated separately from others, has a **low quality**

*Meaning of the sub-characteristics:*
- **Syntactic correctness**: The model in BPMN is syntactically correct if all terms are used in accordance with the syntax rules of the BPMN notation.
- **Changeability**: Support for changes or improvements.
- **Reusability and extensibility**: Support for the model to be used in the creation of new models or extended with new terms.
- **Minimality and simplicity**: If the BPMN model contains the minimum possible constructs.
- **User comprehensibility**: Being understandable by users – both human users and tools.
- **Aesthetics of model**: Focusing on the organization of the BPMN model and improving the look in order to ease its understanding.

**BPMN model A:**

![BPMN Model A Diagram](source: http://www.omg.org/spec/BPMN/2.0/examples/ZIP/)

*Sub-characteristics* | Please rate the class of quality for **BPMN model A**:
--- | ---
Syntactic correctness | Class A  Class B  Class C  Class D  Class E
Changeability | Class A  Class B  Class C  Class D  Class E
Reusability and extensibility | Class A  Class B  Class C  Class D  Class E
Minimality and simplicity | Class A  Class B  Class C  Class D  Class E
User comprehensibility | Class A  Class B  Class C  Class D  Class E
Aesthetics of model | Class A  Class B  Class C  Class D  Class E
BPMN model B:

Sub-characteristics

Syntactic correctness
Changeability
Reusability and extensibility
Minimality and simplicity
User comprehensibility
Aesthetics of model

Please rate the class of quality for BPMN model B:

Class A  Class B  Class C  Class D  Class E

BPMN model C:

Sub-characteristics

Syntactic correctness
Changeability
Reusability and extensibility
Minimality and simplicity
User comprehensibility
Aesthetics of model

Please rate the class of quality for BPMN model C:

Class A  Class B  Class C  Class D  Class E