Quality Marks, Metrics, and Measurement Procedures for Business Process Models

The 3QM-Framework

High-quality business process models are a central prerequisite for a successful process management. Nevertheless, in practice process models often exhibit grammatical, content-related, and stylistic defects. Additionally, very few approaches exist to determine the quality of process models. In this paper, we present the 3QM-Framework which can be used to systematically determine the quality of process models. The 3QM-Framework makes three contributions: it provides quality marks, metrics, and measurement procedures to quantify the quality level as elements of a theoretically justified quality model. The applicability of the 3QM-Framework has been empirically evaluated in case studies. The results of a survey that was conducted among experts moreover attest its practical relevance.

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1 Introduction

As a cornerstone of an efficient process management, the continuous improvement of business processes belongs to the most important challenges in companies today (McDonald and Aron 2010, p. 5). High-quality business process models are an important prerequisite for an efficient process management as they build the methodical basis to communicate and, consequently, to redesign, implement, and control both in-house and intercompany processes (Becker 2011; Hadar and Soffer 2006, p. 569). Accordingly, studies show that already the consistent documentation of process steps along with the executing organizational units can noticeably increase the efficiency of a company's business processes (Melenovsky 2005, p. 4).

Despite their central importance for the process management, in practice business process models often suffer from quality deficits such as violations of the grammar of the modeling notation, content-related, or stylistic defects (Mendling et al. 2008, pp. 313, 326; Fellmann et al. 2011, pp. 27–28). For this reason, it is necessary to systematically assess the quality of created process models (Vanderfeesten et al. 2007, p. 187; Mendling 2009, p. 219). However, literature hardly provides original approaches that support a systematic assessment of the quality of process models. Most quality assurance approaches rather describe constructive procedures which help to satisfy specific quality standards ex ante, i.e. already during the modeling phase. From some of these approaches, relevant quality attributes of process models for a subsequent assessment may be deduced. When doing so, however, it remains unclear how the quality level of business process models should be measured precisely. In particular, frameworks are missing which provide an overview of the distinguishing quality marks of process models and define metrics to measure them. In practice, the quality assessment of process models is, therefore, hardly carried out in a methodical way, but rather in an ad-hoc fashion that is based on the situational knowledge of relevant quality attributes (Mendling 2009, pp. 208–209).

In this paper, we propose the 3QM-Framework as an approach that supports a methodical determination of the quality of business process models. For this purpose, the presented approach specifically makes three contributions: (1) It introduces a theoretically justified quality model that systematically categorizes distinguishing quality marks of business process models. The quality model builds upon earlier contributions which were published in the Business and Information Systems Engineering community and consolidates them into an integrative approach. (2) It defines quality metrics which can be used to quantify the various quality marks. (3) It describes quality measurement procedures that can be used to determine the quality level of business process models.

The construction of the 3QM-Framework is based on the design-oriented research approach of the Business and Information Systems community, especially the design science paradigm (Hevner et al. 2004). This paradigm does not only call for a theoretical foundation and iterative improvement of the design results, but also requires their explicit evaluation. Amongst others, we therefore evaluated the 3QM-Framework in case studies, in which it was applied to determine the quality of business process models. From a scientific viewpoint, we particularly examine the following research questions: Which distinguishing marks determine the quality of business process models? How can these marks be systemized and quantified by the use of metrics? The gathered findings contribute to the building of theories on the quality assurance of business process models and, in particular, to the creation of analytical quality assurance approaches. In this context, especially metrics to measure the quality level have not been sufficiently investigated yet (Mendling 2009, p. 221). Furthermore, the creation of unifying quality models which systematically categorize the distinguishing quality marks of business process models and thereby consolidate existing approaches is viewed to be an important research goal (Moody 2005, p. 268).

In Sect. 2, we discuss related quality assurance approaches to highlight the existing research gap. Thereafter, we describe the research method that the design of the 3QM-Framework is based upon in Sect. 3. In Sect. 4, we present the 3QM-Framework and its elements in detail. Section 5 covers the conducted evaluation of the 3QM-Framework. We conclude by discussing implications for academia and practice as well as the remaining need for future research.

2 Related Work

Approaches to ensure the quality of business process models can generally be categorized into constructive and analytical approaches. Constructive approaches impact the model creation process and are supposed to ensure that a model meets certain quality criteria ex ante (Balzert 2008, p. 477; Sommerville 1992, p. 591; Denger and Olsson 2005, p. 175). Amongst the constructive approaches are e.g. languages, methods, techniques, and guidelines with prescriptions for the model creation process. In contrast, analytical approaches aim at quantifying the achieved quality level and, hence, directly contribute to assessing the model quality (Balzert 2008, p. 477; Sommerville 1992, p. 591; Denger and Olsson 2005, p. 172). Amongst the analytical approaches are in particular classification systems with indicators and measurement procedures.

2.1 Constructive Quality Assurance Approaches

Current literature mainly discusses constructive quality assurance approaches. A focal point is the design and quality evaluation of modeling languages that can be used to depict business processes in high quality (Scheer et al. 2005; OMG 2003, 2007). In this context, research mainly evaluates which contents of business processes should be covered by modeling languages and how different properties of modeling languages affect the quality of the resulting model (Gemino and Wand 2004; Moody 2009; Burton-Jones et al. 2009; Patig et al. 2010; Recker et al. 2011; Mendling et al. 2012). Literature, moreover, examines to what extent current modeling languages already support the creation of high-quality business process models (Indulska et al. 2008; Recker et al. 2009). Constructive quality assurance approaches furthermore comprise modeling techniques that support the meeting of specific quality goals such as the compliance with syntactical rules, terminological conventions, or sequence restrictions (cf. Delfmann et al. 2009; Fellmann et al. 2011). However, the proposed modeling techniques generally do not describe how the achieved quality level can be measured afterwards. Hence, they hardly provide insights into the determination of the quality of business process models. Such insights can rather be derived from modeling guidelines which contain general rules and prescriptions for a high-quality modeling process (Mendling et al. 2010, p. 128). With respect to the quality assurance in business process modeling, especially the Guidelines of Modeling (GoM) and the Seven Process Modeling Guidelines (7PMG) were proposed. Both approaches define specific guidelines to assure the quality of business process models.

The GoM (Becker et al. 1995; Schütte and Rotthowe 1998) build upon earlier approaches for the quality assurance of conceptual data models (Moody and Shanks 1994). They comprise six guidelines that go beyond ensuring syntactical correctness and should generally be considered when designing conceptual models (**Fig. 1**). The provided guidelines aim at improving the quality of the model creation process as well as that of the conceptual model itself. The principle of correctness thereby postulates that the real world excerpt has to be depicted correctly with respect to its content. The principle of relevance prescribes that only elements must be depicted which are relevant for the modeling purpose. The principle of economic efficiency demands that the costs for creating models must not exceed the expected utility. The principle of clarity postulates that a model has to be understandable and readable for the respective users. The principle of comparability requires that models (e.g. as-is and to-be models) have to be created in such a way that their content can be compared with each other. The principle of systematic design finally postulates that multiple views have to be used for the modeling of different aspects which should be adjusted to each other.

Since they were first introduced, the GoM have repeatedly been refined and adjusted according to specific modeling purposes, amongst others for the modeling of business processes (Becker et al. 2000). However, they do not contain concrete measures to achieve the mentioned goals, which makes their practical application during the modeling process difficult (Schütte 1998, p. 12; Mendling et al. 2010, p. 128). Moreover, it is difficult to use the GoM to determine the quality of business process models. Although some of the guidelines can be used to derive quality marks that have to be evaluated, concrete metrics which prescribe how

Fig. 1 Guidelines of Modeling (GoM, according to Becker et al. 2000, p. 32)

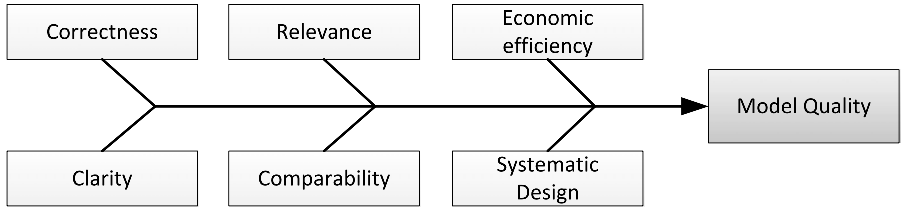
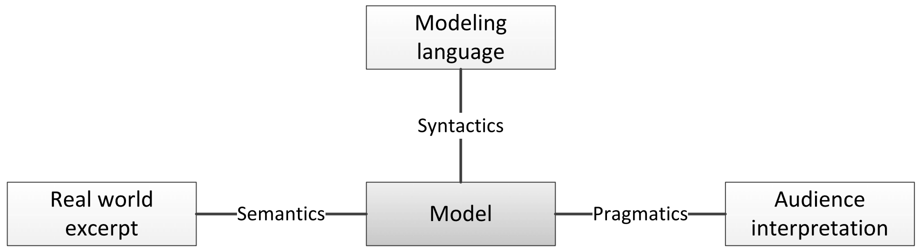


Fig. 2 Semiotic Quality Model (SEQUAL, Lindland et al. 1994, p. 44)



those quality marks can be measured are missing. Furthermore it remains unclear how complete a quality assessment on the basis of the GoM would be and how the different marks should be weighted against each other.

The 7PMG (Mendling et al. 2010) aim at improving the understandability and the manageability of business process models. Based on the observation that content can be depicted more or less efficiently, concrete measures are proposed to keep the complexity of process models low. The proposed measures affect the modeling style, i.e., the modeler's use of the language. In particular, the 7PMG recommend to minimize the number of modeling elements as well as the number of in- and outgoing connections, to use only one start- and one end-element, to split and merge control flow parts with analogous connectors, to label activities with a verb and an object, to avoid inclusive OR connectors, and to decompose models that consist of more than 50 elements. The 7PMG can be used to determine the quality of business process models as concrete quality marks can be derived from the guidelines. Moreover, metrics exist which can quantify these quality marks (Vanderfeesten et al. 2007, p. 180). Yet, it remains unclear if the derived quality marks support a comprehensive assessment of the modeling style. Compared to the syntactic and semantic correctness of process models, assessing the modeling style moreover appears to be less relevant for the moment, although a high-quality modeling style admittedly contributes to mitigating modeling faults and to improving the maintainability (Mendling et al. 2010, p. 218).

2.2 Analytical Quality Assurance Approaches

Analytical quality assurance approaches are comparably seldom discussed in literature. To determine the quality of business process models, in particular the Semiotic Quality Model (SEQUAL) can be used. Proposed by Lindland et al. (1994), SEQUAL uses the general linguistic theory of signs as kernel theory. It systematically distinguishes between quality aspects of conceptual models which refer to the modeling language used, the depicted real world excerpt, and the interpretation of a model by its audience (**Fig. 2**). The syntactic quality depicts to what extent a model complies with the formal rules of the modeling language. The semantic quality describes the level of equivalence between the real world excerpt and the model content. The pragmatic quality characterizes the interpretability of the model by its users. In the course of time, several influencing factors such as the knowledge of the modeler have been identified as determinants of the quality aspects and were hence included in the model (Krogstie et al. 2006, p. 98).

SEQUAL further describes requirements and exemplary quality marks for the described quality aspects. However, the quality marks are neither explicitly defined nor listed completely. Moreover, it is not mentioned how the quality marks can be quantified. Although empirical studies have shown that the quality aspects of SEQUAL are perceived to be complete during the assessment of business process models (Moody et al. 2003, p. 299), participants assigned numerous deficits of the models either to a wrong quality aspect or to none at all. A major reason for this was that the quality marks are only very vaguely or not at all described in SEQUAL (Moody et al. 2003, p. 301). Due to its high degree of abstraction, the practical applicability of SEQUAL to determine the quality of conceptual models is limited (Shanks and Darke 1997, p. 805).

To mitigate the weaknesses of current approaches, a systematical development of analytical frameworks to support the quality determination has been demanded in literature (Moody 2005, p. 268). In particular, requirements are described that should be met by such frameworks. On the one hand, new frameworks should be based on the structure of established frameworks that determine the quality of software such as the ISO 9126 standard (R1; Moody 2005, p. 252). Furthermore, existing approaches should be considered and consolidated during the development of new frameworks (R2; Moody 2005, p. 266). On the other hand, concrete requirements with regard to the content of such frameworks exist. Basically, frameworks to determine the quality should define and categorize relevant quality marks (R3), determine metrics to quantify the quality marks (R4), and support a weighting of quality marks (R5) to determine their relative importance. Moreover, they should name relevant user groups (R6), which have to be comprised by the assessment, and outline measures (R7) that must be performed when quality defects are identified (Moody and Shanks 1994, p. 97; Shanks and Darke 1997, p. 809). Finally, frameworks should be confirmed by experts (R8) to ensure their acceptance in practice (Moody 2005, p. 267).

Besides the above-mentioned approaches, further work exists that concentrates on the quality determination of conceptual models. In particular, a set of approaches which can be used to determine the perceived model quality has been proposed (Poels et al. 2005, p. 378; Krogstie et al. 2006, p. 98). The focus of such approaches, though, is not to determine the actual quality of conceptual models. Rather, potential users are asked for their perception of the quality level in order to evaluate their willingness to use those models. Since the 3QM-Framework aims at supporting the evaluation of the factual, objectively measurable model quality, we did not consider approaches to determine the perceived model quality.

3 Research Method

The construction of the 3QM-Framework is based on the design science paradigm that introduces principles for the scientific construction of innovative artifacts (Hevner et al. 2004, p. 77). In terms of this paradigm, artifacts may be constructs, models, methods, and instantiations which help solving relevant problems regarding the planning and implementation of information systems in companies (March and Smith 1995, p. 253). To ensure a scientific construction of such artifacts, especially two principles have to be followed. On the one hand, a novel contribution that extends the current knowledge base has to be provided with the construction of the artifact (Hevner et al. 2004, p. 83). For this, it not only has to be verified that the respective research goals have been met (Iivari 2007, pp. 50–51). As design science research aims at solving relevant problems, additionally the usefulness of the artifact has to be evaluated (March and Smith 1995, p. 253). On the other hand, the construction of the artifact has to be carried out in a traceable, rigorous manner (Iivari 2007, pp. 50–51). To achieve the latter, a structured design process has to be followed that is based upon explicitly defined requirements (Iivari 2007, p. 50; Hevner et al. 2004, p. 88). Moreover, it is recommended to build upon so-called kernel theories that form a scientific fundament for the construction of artifacts (Hevner et al. 2004, p. 80).

With the 3QM-Framework, we particularly aim at contributing to the closure of the research gap that was discussed in Sect. 2. Accordingly, the research goal associated with its design is basically to fulfill the requirements for quality assessment frameworks (R1–R8) as listed in Sect. 2. In a first step, however, we focused on satisfying the fundamental requirements R1–R5 during our research project. To ensure a broad applicability of the 3QM-Framework, we furthermore wanted it to be usable independently of the notation used to model business processes. The universality of the approach (R9), hence, constituted another requirement for the design of the 3QM-Framework.

During the design of the 3QM-Framework, whose elements qualify as artifacts according to the taxonomy above, we carefully incorporated the two mentioned principles for design science research projects. We implemented two measures to ensure the rigorousness of the design. On the one hand, we systematically based the design of the 3QM-Framework on a kernel theory that determines the distinguishing quality marks which have to be taken into account from a theoretical point of view (Sect. 4). On the other hand, we adopted the design cycle, a structured process model introduced by Takeda et al. (1990) and refined by Vaishnavi and Kuechler (2004) for the usage in design science research projects. This process model supported the iterative construction and evaluation of the 3QM-Framework. All in all, we passed through four iterations of the design cycle until we reached the version that is presented in the work at hand. During these iterations, the 3QM-Framework was repeatedly evaluated in order to verify its usefulness and the achieved scientific contribution. To prove the usefulness of the 3QM-Framework, we specifically evaluated in how far it supports the measuring of practically relevant deficits of business process models and in how far it supports the reliable, unequivocal assignment of such deficits to quality marks (Sect. 5). These two properties are denominated as adequacy and reliability in literature and viewed to be two major determinants for the usefulness of design results (Hevner et al. 2004, p. 85). To verify the achieved scientific contribution, we furthermore examined in how far the 3QM-Framework met the aspired research goal . For this purpose, we evaluated the fulfillment of the requirements R1–R9 (Sect. 6).

4 The 3QM-Framework

The 3QM-Framework aims at supporting a methodical determination of the quality of business process models. In reference to the quality definition provided by the ISO 9000 standard (ISO/IEC 2000), the quality of a business process model can generally be defined as the totality of its characteristics that bear on its ability to satisfy stated requirements. Above all, literature emphasizes the ability of business process models to communicate model contents as a central requirement, e.g., for the purpose of redesigning, implementing, or controlling business processes (Becker 2011; Hadar and Soffer 2006, p. 569). Additional requirements, e.g., with respect to the maintainability or changeability of business process models, furthermore ought to be fulfilled to facilitate the process management (Vanderfeesten et al. 2007, p. 179). The 3QM-Framework particularly addresses the quality of process models as means of communication. Its quality marks, metrics, and measurement procedures hence specifically contribute to determining the appropriateness of business process models to communicate model contents.

4.1 Kernel Theory

Business process models are created during a modeling process in which an excerpt of the real world is perceived by a modeler and depicted using a modeling language (Hadar and Soffer 2006, p. 573). The resulting model is a description of the perceived real world excerpt in natural or a graphical language. From a linguistic point of view, it is a sequence of signs – a so-called sign system – which represents the real world excerpt (Sebeok and Danesi 2000, pp. 1–2). The appropriateness of sign systems as means of communication can be explained with semiotics, i.e., the theory on the nature and usage of linguistic signs (Morris 1938, p. 2; Sebeok 2001, p. 3; Martin and Ringham 2006, p. 175). In semiotic theory, a sign is not merely conceived as a static thing, but as a triadic relation between the sign itself (the so-called signifier or sign vehicle) as the communication medium, the signified (the so-called referent or designatum) as the referenced real world object, and the sense (the so-called interpretant or thought) as the conception that is evoked by the sign (Morris 1938, p. 3; Nöth 1990, p. 89).

According to this relation, semiotic theory distinguishes three fundamental properties of signs and sign systems which are subsumed under the categories syntactics, semantics, and pragmatics (Morris 1938, pp. 6–7; Martin and Ringham 2006, p. 155). Syntactics covers the relationships between the signs of a sign system. It describes the formal order of signs and sign sequences and so characterizes the structure of the sign system. Semantics contemplates the relationships between the signs and the signified. It describes the reference of signs and sign sequences to objects of the real world excerpt and so characterizes the meaning of a sign system. Pragmatics focuses on the relationships between the signs and the interpreter. It describes the interpretation of signs and sign sequences by the recipient and so characterizes the mental processing of a sign system. The three fundamental categories of properties determine the quality of sign systems as means of communication in general (Morris 1938, pp. 1–2, 10). They are not dependent on the sign format and can hence be used to analyze textual and graphical signs alike (Morris 1938, p. 1). Therefore, they also have to be considered when determining the quality of business process models as means of communication.

4.2 Quality Marks

The 3QM-Framework builds upon semiotics as kernel theory. It takes over syntactics, semantics, and pragmatics as fundamental quality marks of business process models and systematically operationalizes them further. Following the ISO 9126 standard to determine the quality of software artifacts, we developed a quality model with a hierarchy of quality marks, specific sub-marks, and metrics during this operationalization (ISO/IEC 2001, p. 7). **Figure 3** depicts the quality model in a graphical summary.

The quality mark syntactics specifies in how far a business process model adheres to the formal rules of the modeling language. Mandatory formal rules result from both the lexicon, which predetermines the available words as the repertoire of signs, and the grammar, which regulates the combination of words to complex statements (Morris 1938, p. 14; Martin and Ringham 2006, p. 95). For instance, the Event-Driven Process Chain (EPC) and the Business Process Model and Notation (BPMN) each define a vocabulary with specific words in the form of graphical signs and a specific grammar with rules for the combination of these signs. Depending on the respectively contemplated formal rules, semiotics distinguishes between the word syntax (morphology), the sentence-level syntax, and the text syntax (discursive syntax) as sub-categories (Morris 1938, p. 14; Martin and Ringham 2006, pp. 196–197). Based on these sub-categories, the quality determination of the syntactics of business process models can be further concretized.

The sub-mark word syntax specifies in how far the formal regulations of the lexicon are adhered to (Morris 1938, p. 14; Martin and Ringham 2006, p. 128), i.e., to which degree the signs depicted in a business process model correspond to the lexicon of the modeling language. When using the BPMN, for instance, events always have to be depicted with a circle (**Fig. 4, I**) while they have to be represented with a hexagon in an EPC. If signs that do not belong to the used language are depicted in a business process model, the word syntax is compromised. This negatively affects the communication of the model contents as the formal meaning of the unexpected signs is unclear for the model interpreter.

The sub-mark sentence-level syntax focuses on the direct combination of words to form larger units according to the grammar, the so-called sentence structure (Morris 1938, pp. 14–15; Sebeok and Danesi 2010, p. 1077). It specifies in how far a business process model adheres to the rules of the grammar that predetermine the combination of individual words to larger units (sentences). Through the combination of words, it is for instance possible to formulate statements about the temporal sequence of activities whose formal meaning is determined by the grammar of the modeling language. However, the words of a modeling language cannot be combined in an arbitrary manner. In EPC, for example, events must not stand before a conditional branch of the control flow, i.e., they must not determine which path to follow. The BPMN's grammar makes no comparable restriction. Within a process flow, however, it only allows the usage of so-called intermediate events that have to be depicted with a double border (**Fig. 4, II**). If such rules are violated during the modeling, the formal meaning of the resulting statements is unclear for the interpreter. This complicates the communication of the model contents.

The sub-mark text syntax covers the combination of sentences to form complex expressions, i.e., the transitive combination of words to form texts (Sebeok and Danesi 2010, p. 1097; Martin and Ringham 2006, p. 197). It specifies to which degree a business process model conforms to the rules of the grammar which govern the combination of sentences to form complex expressions. Typically, formal relationships between individual sentences exist which have to be observed when formulating complex expressions as a text. Such relationships for instance exist between splits and merges of control flow parts, which have to be depicted by so-called connectors in EPC and BPMN. In doing so it has to be kept in mind that the connectors used to depict the merge of control flow parts should be formally compatible to those connectors used to split the parts earlier on (**Fig. 4, III**).

The quality mark semantics specifies in how far the reference of the model elements to real world objects is appropriate, i.e., to which degree the underlying real world excerpt is adequately depicted in the model (Morris 1938, pp. 21–22; Martin and Ringham 2006, p. 171). Generally, the semantics of a sign system is determined by its carriers of meaning (Morris 1938, p. 24). According to semiotic theory, a sign in a sign system is a carrier of meaning if it is linked to a real world object that has to be depicted in order to communicate a certain part of reality (Morris 1938, p. 25). To analyze the semantics of a business process model, its business process specific carriers of meaning hence have to be examined. These, amongst others, include all signs that depict activities which have to be performed, temporal dependencies, or participating organizational units. As relevant sub-marks to determine the semantics of business process models, literature particularly emphasizes the categories completeness, correctness, and relevance (Becker et al. 2000, p. 32; Lindland et al. 1994, p. 46; Moody and Shanks 1994, p. 101). In the 3QM-Framework, these sub-marks are complemented by the category flexibility, which we have defined in addition to correctness.

The sub-mark completeness is concerned with the presence of the carriers of meaning that are required to communicate a real world excerpt. It specifies in how far all contents required to understand the real world excerpt are depicted by model elements. For instance,

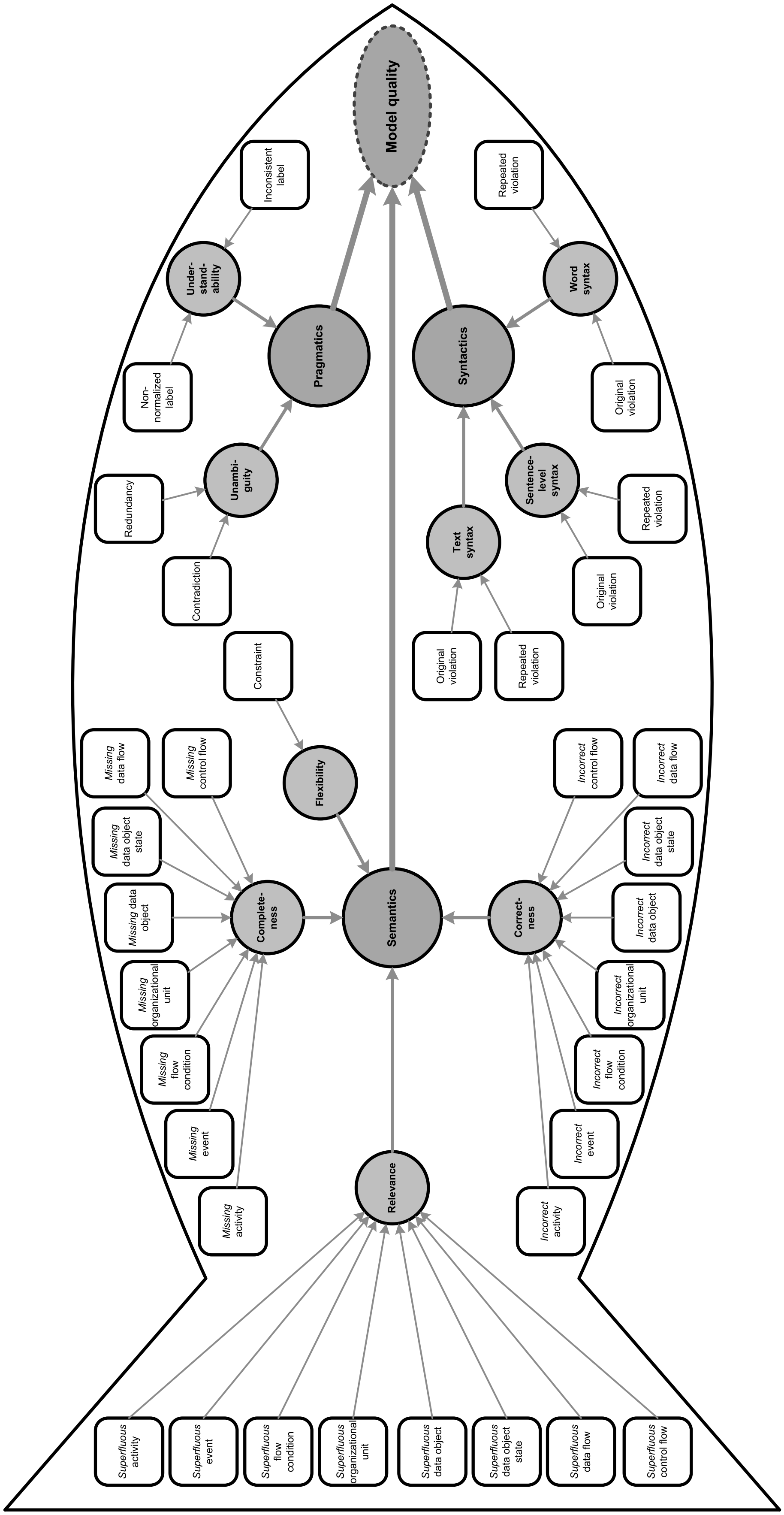


Fig. 3 Quality model of the 3QM-Framework with quality marks (*gray*) and metrics (*white*)

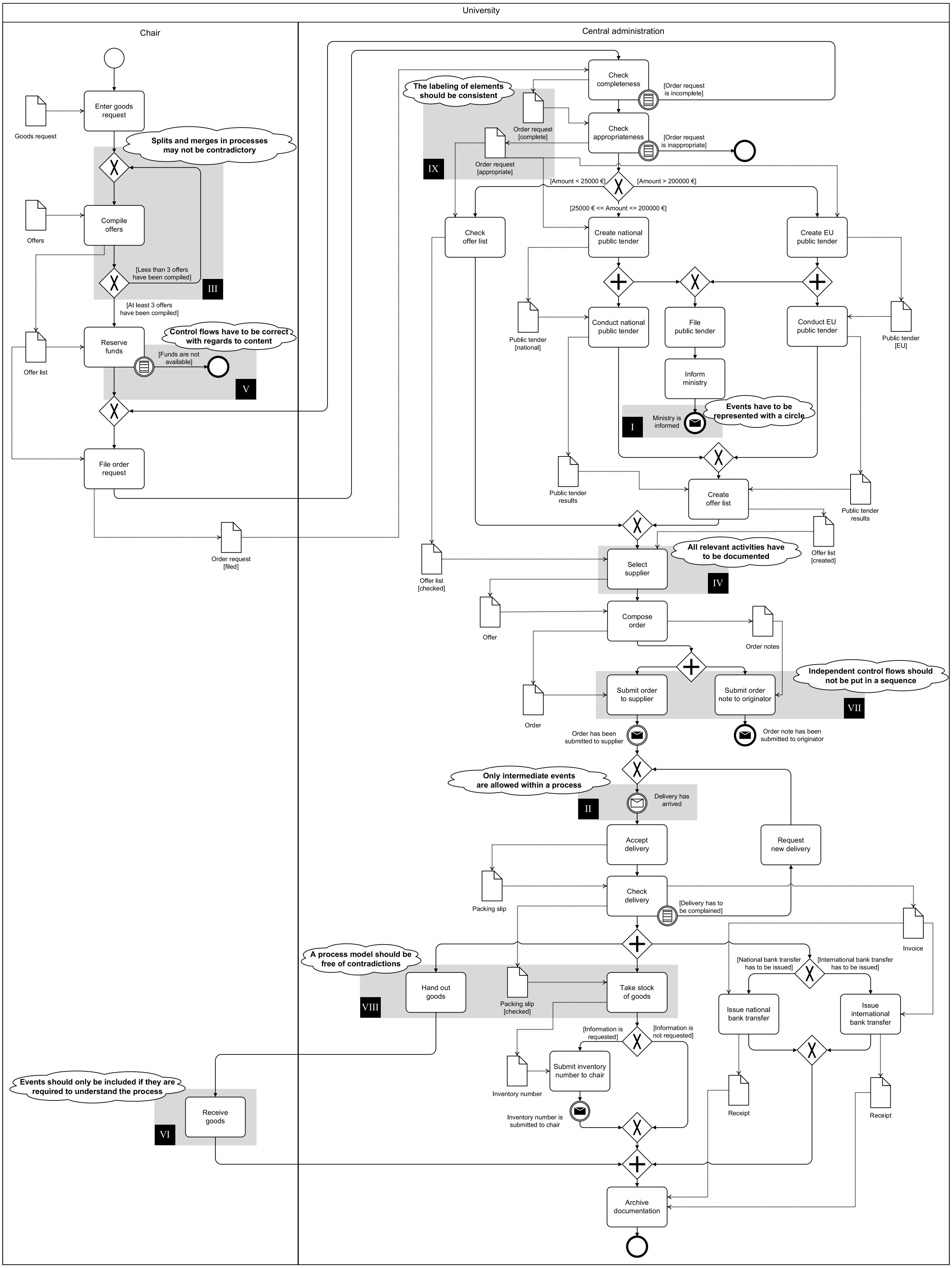


Fig. 4 Procurement process at a German university (depicted in BPMN)

it is necessary to document all work steps that have to be performed during a business process as activities in the model (**Fig. 4, IV**). If relevant aspects of a business process remain undocumented in the model, the interpreter can at best infer them from the context. This negatively affects the ability of the business process model to effectively communicate the underlying real world excerpt.

The sub-mark correctness inspects the content reference of the carriers of meaning that are depicted in a business process model. It specifies in how far the meaning of the model elements is consistent to the real world excerpt that has to be depicted. For instance, all activities and control flow parts that are depicted in a model have to be correct as regards content (**Fig. 4, V**). If aspects of a business process model are incorrectly depicted with respect to the content, i.e. if their reference deviates from the real world excerpt that actually has to be represented, a defective understanding of the process is created. This compromises the appropriateness of a business process model as a means of communication.

In this context, flexibility specifically addresses the independence of individual control flow parts that are depicted in a business process model. The sub-mark specifies in how far actually independent parts of the control flow are depicted as concurrent in the model. Ideally, independent parts of the control flow always ought to be depicted as parallel control flows (**Fig. 4, VII**). If they are instead depicted as a sequence, i.e., as proceeding one after another, only one possible course of action among the actually possible ones is specified. In principle, this negatively affects the ability of the business process model to appropriately communicate the underlying real world excerpt (e.g., in order to support a planned process optimization). Sometimes, however, independent parts of the control flow are deliberately depicted in sequence to reduce the complexity of the process model and increase its appropriateness as a means of communication. Studies have shown that especially the number of branches and merges negatively affects the comprehensibility of business process models (Mendling 2008). As the sequential representation at least correctly depicts one of the possible courses of action, we decided to measure this aspect using a separate category when designing the 3QM-Framework.

The sub-mark relevance contemplates the necessity of the carriers of meaning that are depicted in a business process model. It expresses in how far the model elements are required to communicate a particular real world excerpt. A business process model should for instance only contain those activities and events which are required to communicate the underlying real world excerpt (**Fig. 4, VI**). Depicting superfluous aspects in a business process model, which have no direct reference to the real world excerpt that is to be depicted, increases the complexity for the interpreter. This negatively affects the communication of the contents which have to be transported with the model.

The quality mark pragmatics specifies in how far the presentation of the business process model supports the interpretation of the contents which have to be communicated (Martin and Ringham 2006, p. 155). To this end, semiotic theory amongst others contemplates linguistic forms of expression and strategies to formulate statements that facilitate a cooperative interpretation of what was meant (Morris 1938, pp. 36–37; Nöth 1990, pp. 28, 47). Here the focus is also on the circumstances under which the effect of signs, i.e., the conception that is evoked during their interpretation, is negatively affected by deficits regarding the intuitiveness of the formulation (Morris 1938, p. 37). This aspect of pragmatics is particularly important when determining the quality of business process models. It encompasses unambiguity and understandability as relevant subcategories, which affect the understanding that is evoked during the interpretation of the model (Morris 1938, p. 37; Nöth 1990, p. 54).

The sub-mark unambiguity contemplates the interpretability of the formulations that are contained in a business process model from a content-oriented perspective. It specifies in how far the elements of the model are intuitively formulated with respect to content (Nöth 1990, p. 54). For instance, a business process model should not contain any contradictions (**Fig. 4, VIII**). If the elements of the business process model do not intuitively describe the content, its interpretation by the model user is complicated. This negatively affects the ability of the business process model to efficiently communicate the underlying real world excerpt.

The sub-mark understandability focuses on the interpretability of the formulations that are contained in a business process model from a language-usage perspective. It specifies in how far the use of the language to formulate the model elements is intuitive (Nöth 1990, p. 54). For instance, the labeling of elements should not be modified through the use of synonyms in the business process model (**Fig. 4, IX**). Any use of the language that is not intuitive for the model user negatively affects the interpretation of the depicted real world excerpt and, accordingly, the appropriateness of the business process model as a means of communication.

4.3 Metrics and Measurement Procedures

In order to evaluate to what extent business process models meet the previously defined quality criteria, we defined a catalog of concrete metrics and measurement procedures for the 3QM-Framework (**Table 1**). The defined metrics contain measurement indices which support measuring the level of the individual quality criteria. The measurement procedures thereby specify how the individual measurement indices are to be determined. On the basis of the proposed metrics and measurement procedures, the quality marks of the 3QM-Framework can, hence, be systematically quantified. Compared to approaches which solely define quality criteria without describing how they are to be quantified, the 3QM-Framework thus enables a more objective, unequivocal determination of the quality of business process models.

The 3QM-Framework moreover distinguishes between absolute and relative measurement procedures respectively (**Table 1**). Absolute measurement procedures help to assess the overall extent of a measurement. Relative measurement procedures set the determined absolute value in relation to the size of the model. They can hence be used to determine the quality level independently of the model size. Relative measurement procedures are therefore particularly suited to compare the quality level of different models, while absolute measurement procedures are better suited to assess the effort required to improve a particular business process model. The syntactic quality can solely be measured on the basis of the business process model

Table 1 Metrics and measurement procedures of the 3QM-Framework

Name of the metric	Purpose	Measurement procedure	Scale	Preference
Syntactics				
Word syntax				
Original violation	How formally correct are specific language constructs modeled?	A=Number of language constructs that are modeled incorrect for the first time R=1-A/(Number of overall modeled language constructs)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Repeated violation	How often are specific language constructs modeled formally incorrect?	A= Number of language constructs that are repeatedly modeled incorrect R=1-A/(Number of overall modeled language constructs)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Sentence-level syntax				
Original violation	How formally correct are direct combinations of language constructs modeled?	A= Number of direct combinations that are modeled incorrect for the first time R=1-A/(Number of overall modeled direct combinations)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Repeated violation	How often are direct combinations of language constructs modeled formally incorrect?	A= Number of direct combinations that are repeatedly modeled incorrect R=1-A/(Number of overall modeled direct combinations)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Text syntax				
Original Violation	How formally correct are transitive combinations of language constructs modeled?	A= Number of transitive combinations that are modeled incorrect for the first time R=1-A/(Number of overall modeled transitive combinations)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Repeated Violation	How often are transitive combinations of language constructs modeled formally incorrect?	A= Number of transitive combinations that are repeatedly modeled incorrect R=1-A/(Number of overall modeled transitive combinations)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Semantics				
Correctness				
Incorrect flow condition	How correctly are the flow conditions of the real world excerpt depicted?	A=Number of flow conditions that are not consistent with the real world excerpt R=1-A/(Number of overall modeled flow conditions)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect activity	How correctly are the activities of the real world excerpt depicted?	A=Number of activities that are not consistent with the real world excerpt R=1-A/(Number of overall modeled activities)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect data flow	How correctly are the data flows of the real world excerpt depicted?	A=Number of data flows that are not consistent with the real world excerpt R=1-A/(Number of overall modeled data flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect event	How correctly are the events of the real world excerpt depicted?	A=Number of events that are not consistent with the real world excerpt R=1-A/(Number of overall modeled events)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect data object	How correctly are the data objects of the real world excerpt depicted?	A=Number of data objects that are not consistent with the real world excerpt R=1-A/(Number of overall modeled data objects)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect data object state	How correctly are the data objects states of the real world excerpt depicted?	A=Number of data object states that are not consistent with the real world excerpt R=1-A/(Number of overall modeled data object states)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect control flow	How correctly are the control flows of the real world excerpt depicted?	A=Number of control flows that are not consistent with the real world excerpt R=1-A/(Number of overall modeled control flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Incorrect organizational unit	How correctly are the organizational units of the real world excerpt depicted?	A=Number of organizational units that are not consistent with the real world excerpt R=1-A/(Number of overall modeled organizational units)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Relevance				
Superfluous flow condition	Are solely the relevant flow conditions of the real world excerpt depicted?	A=Number of flow conditions that can be eliminated without losing information R=1-A/(Number of overall modeled events)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous activity	Are solely the relevant activities of the real world excerpt depicted?	A=Number of activities that can be eliminated without losing information R=1-A/(Number of overall modeled activities)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous data flow	Are solely the relevant data flows of the real world excerpt depicted?	A=Number of data flows that can be eliminated without losing information R=1-A/(Number of overall modeled data flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous event	Are solely the relevant events of the real world excerpt depicted?	A=Number of events that can be eliminated without losing information R=1-A/(Number of overall modeled events)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous data object	Are solely the relevant data objects of the real world excerpt depicted?	A=Number of data objects that can be eliminated without losing information R=1-A/(Number of overall modeled data objects)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous data object state	Are solely the relevant data object states of the real world excerpt depicted?	A=Number of data object states that can be eliminated without losing information R=1-A/(Number of overall modeled data object states)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous control flow	Are solely the relevant control flows of the real world excerpt depicted?	A=Number of Number of an control flows that can be eliminated without losing information R=1-A/(Number of overall modeled control flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Superfluous organizational unit	Are solely the relevant organizational units of the real world excerpt depicted?	A=Number of organizational units that can be eliminated without losing information R=1-A/(Number of overall modeled organizational units)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Completeness				
Missing flow condition	How complete are the flow conditions of the real world excerpt depicted?	A=Number of flow conditions that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled flow conditions)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing activity	How complete are the activities of the real world excerpt depicted?	A=Number of activities that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled activities)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing data flow	How complete are the data flows of the real world excerpt depicted?	A=Number of data flows that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled data flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing event	How complete are the events of the real world excerpt depicted?	A=Number of events that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled events)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing data object	How complete are the data objects of the real world excerpt depicted?	A=Number of data objects that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled data objects)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing data object state	How complete are the data object states of the real world excerpt depicted?	A=Number of data object states that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled data object states)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing control flow	How complete are the control flows of the real world excerpt depicted?	A=Number of control flows that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled control flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Missing organizational unit	How complete are the organizational units of the real world excerpt depicted?	A=Number of organizational units that are missing compared to the real world excerpt R=1-A/(A + Number of overall modeled organizational units)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Flexibility				
Constraint	Are flows that are independent in the real world excerpt modeled as parallel control flows?	A=Number of flows where the flexibility is limited compared to the real world excerpt R= 1-A/(Number of overall modeled control flows)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Pragmatics				
Unambiguousness				
Redundancy	How free of redundancies is the modeled process?	A= Number of process elements that were modeled redundantly R= 1-A/(Number of overall modeled process elements)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Contradiction	How free of contradictions is the modeled process?	A= Number of process elements that logically contradict each other R= 1-A/(Number of overall modeled process elements)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Understandability				
Inconsistent label	To what extent are the labels used in the model consistent?	A= Number of labels that vary within the model R= 1-A/(Number of overall modeled labels)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending
Non-normalized label	To what extent do the labels used in the model adhere to established conventions?	A= Number of labels that violate established conventions R= 1-A/(Number of overall modeled labels)	$A \in \mathbb{N}$ $R \in [0;1]$	Descending Ascending

itself and the formal rules of the modeling language that was used. As the business process model is only verified against formal criteria during the measurement of syntactical quality marks, no additional knowledge about the underlying real world excerpt is required. However, when determining the semantics or pragmatics, the reference of the model to the real world excerpt has to be examined. This step comprises a validation of the content which has to be achieved either on the basis of a documentation of the real world excerpt or on the basis of the reality as perceived by model users. If the validation is to be conducted on the basis of the perceived reality, business experts with privileged insights into the real world excerpt that is depicted in the model ought to be consulted.

Quantifying the sub-marks of the syntactic quality is carried out in a common procedure that can be used to measure the word syntax, the sentence-level syntax, and the text syntax. The metrics of the sub-marks measure if the respective formal rules of the used modeling language are violated. Here we distinguish between original violations and repeated violations, which are recorded independently of each other (**Table 1**). Original violations occur whenever a formal rule of the modeling language is violated for the first time. The number of original violations hence describes how many different rules of the modeling language are violated. In contrast, the number of repeated violations specifies how often formal rules are violated. For example, if an activity is depicted with a circle in a BPMN model for the first time, this has to be measured as an original violation in the category word syntax. If activities are repeatedly depicted in this manner, every further violation is counted as repeated violation.

The distinction between original and repeated violations is based on the assumption that the first violation of a formal rule more severely compromises the appropriateness of a business process model as a means of communication than further, repeated violations. When studying a syntactically defective model, the user not only has to identify the violations of the rules, but also has to determine what the modeler actually meant to depict. An additional cognitive load especially arises when novel violations of rules must be processed. Repeated violations of rules that the user already is familiar with typically do not cause such a cognitive load anymore. Besides, separating original and repeated violations of rules enables analysts to identify if merely some formal rules of the used modeling language lead to mistakes or if the modeling grammar as a whole is difficult to use. The results of such an analysis can, e.g., be used to reevaluate the applicability of a modeling language that is employed by a company during the process management.

To measure the quality level of the sub-marks contained in the category semantics, the relevant carriers of meaning of a business process model have to be inspected. The relevant carriers of meaning to depict a business process have been discussed in literature. Literature particularly emphasizes the signs to represent activities, events, flow conditions, organizational units, data objects, data object states, data flows, and control flows to be relevant carriers of meaning (Becker and Schütte 2004, p. 107; Weske 2007, pp. 88–120; Recker et al. 2009, p. 341). To measure completeness and correctness, the number of missing carriers of meaning (completeness) and incorrect carriers of meaning (correctness) has to be documented during a comparison of the business process model with the underlying real world excerpt. Thereby, the number of superfluous carriers of meaning, i.e., carriers of meaning that can be eliminated without loss of information, has furthermore to be determined in order to measure the relevance. The flexibility results from the number of control flow constraints which has to be determined during the comparison of the business process model with the underlying real world excerpt. Here a constraint emerges each time when actually independent control flows are connected to each other in sequence.

Table 1 summarizes the specific metrics and measurement procedures for the individual carriers of meaning in business process models. When designing the 3QM-Framework, we only defined metrics and measurement procedures for carriers of meaning which are used in various business process modeling languages. Depending on the modeling language used, additional signs might exist that depict relevant contents and that should hence also be considered during the quality determination. Metrics and measurement procedures for such language-specific carriers of meaning can be developed in analogy to those depicted in **Table 1** and be included into the framework as needed.

To determine the quality level of the sub-marks contained in the category pragmatics, the intuitiveness of the depicted model elements with respect to the content and the intuitiveness of the language use have to be examined. In accordance with findings of the semiotics discipline, we defined the two metrics redundancy and contradiction in order to measure the intuitiveness with respect to the content (Nöth 1990, p. 54). The first metric measures the number of carriers of meaning which are unnecessarily depicted repeatedly in a business process model. This, for instance, applies to any activities that are recurrently depicted in individual threads of parallel flows. The second metric measures the number of process elements that are semantically correct, but logically in contradiction to other model elements or the control flow. Such a contradiction can for instance result from a conflict with the token semantics of certain modeling languages, which can cause a blocking of repetitive control flow parts.

Building upon findings from the semiotics discipline, we introduced the two metrics non-normalized labels and inconsistent labels to measure the intuitiveness of the language use (Nöth 1990, p. 54). The first metric measures the number of violations of labeling conventions. By adhering to labeling conventions, the understandability of business process models can generally be improved (Mendling et al. 2010, p. 130). Therefore, companies often have labeling conventions that have to be maintained. An established convention for example demands that activities are labeled with a verb in the infinitive and an object. The second metric measures how often carriers of meaning are labeled inconsistently within a process model. Using different synonymous labels for model elements compromises the understandability of business process models as the connection between those elements is not immediately evident for the model users anymore.

The metrics to measure the quality level in the category pragmatics are summarized in **Table 1**. It has to be mentioned that further approaches exist besides those metrics, which can be used to examine the intuitiveness of the language use. To gain information about the intuitiveness of graphical models, it is for instance possible to apply the criteria and metrics provided by the 7PMG. They support an analysis of the graphical layout's clarity. Yet, graphical modeling

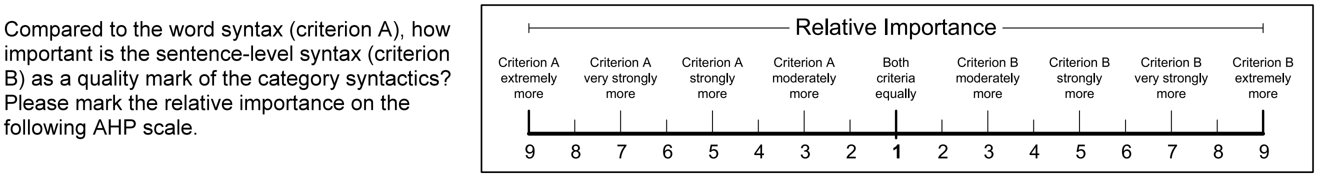


Fig. 5 Exemplary pairwise comparison and AHP scale (according to Saaty 1980, pp. 18, 53–64)

formats are only one way to depict business process models. Especially in practice, formats based on natural language are also widely used to depict business process models (Patig et al. 2010, p. 24). When designing the 3QM-Framework, we therefore focused on developing metrics and measurement procedures that can be used across specific modeling formats.

4.4 Aggregation

The metrics of the 3QM-Framework initially support an assessment of individual quality marks. In order to make a statement about the overall quality of a process model, the individual measurements have to be aggregated over the different hierarchy levels of the quality model. In the course of this, however, the importance of individual quality marks can vary depending on the project context (Moody and Shanks 1994, p. 100). Hence, when conducting the aggregation, the situation and all relevant user groups have to be considered to derive a weighing of all quality marks and metrics. The 3QM-Framework therefore uses the Analytic Hierarchy Process (AHP). The AHP supports the participating user groups by decomposing the decision problem into pairwise comparisons on the basis of a verbalized scale (Saaty 1994, pp. 35, 40). Pairwise comparisons here have to be conducted for all quality marks and metrics that are summarized by higher-level marks of the quality model (**Fig. 5**).

If the weightings are to be derived from multiple participants, their results have to be summarized by calculating the geometric mean for each comparison (Aczél and Saaty 1983, p. 101; Saaty 1986, p. 854). For the analysis, the mean values are to be denoted into a matrix which can be used to determine the weightings by eigenvalue calculations (for the calculation procedure cf. Saaty 1980, pp. 22–24). To ensure that the pairwise comparisons do not contradict each other, the consistency ratio CR for the comparisons has to be evaluated as an indicator for potential problems. If this ratio is below the commonly accepted threshold of 10 %, the weightings derived with the AHP are deemed to be usable (Saaty 1980, p. 51).

5 Evaluation

The 3QM-Framework was repeatedly evaluated during the four design cycles. First of all, we examined its usefulness. Based on the results, we further refined the framework until a version had been achieved that was stable regarding its usefulness. Utilizing this version, we analyzed the agreement of experts and, hence, the external validity of the 3QM-Framework. Finally, we examined in how far a unified weighting suggestion can be achieved for the before-described aggregation.

5.1 Usefulness

Case studies were implemented at the end of the design cycles to analyze the usefulness of the 3QM-Framework. During the case studies, we analyzed the reliability of the defined quality marks and metrics as well as their adequacy to determine the quality of business process models (Hevner et al. 2004, p. 85). The reliability of the quality marks and metrics describes in how far their application leads to reproducible results during the quality determination. The adequacy shows to which degree they contribute to the identification and classification of quality defects in business process models.

To ensure a continuous evaluation of the usefulness, the executed case studies were based on the same design. Each time, a qualitative analysis was used to examine the results. Basically, quantitative examination methods are likewise suitable to analyze the usefulness of the 3QM-Framework. For example, quantitative measures like Cronbach's Alpha or Cohen's Kappa would also allow evaluating the reliability of the defined quality marks and metrics. However, quantitative methods can hardly be used to explain why certain results have been achieved. Qualitative methods, on the other hand, support the description, interpretation, and comprehension of the context and, therefore, allow a more comprehensive analysis of problems and causalities (Given 2008, p. xxix). Hence, a qualitative evaluation was particularly suited for the exploration of remaining weaknesses during the design cycles.

In each case study, several quality assessors compared handwritten business process models with a documentation of the underlying real world excerpt. Based on the provided metrics, all quality defects had to be measured and assigned to the quality marks of the 3QM-Framework. To better support the generalizability of the results, different business process models that were documented in varying notations were examined during the case studies. Thereby, graphical models in UML, BPMN, and EPC, as well as natural-language based models notated in normative language were analyzed. The quality assessors were faculty members at a university and had several years of professional experience. Within their jobs they were engaged in modeling business processes in research, teaching and industry projects. The assessors worked together in a group during the quality determination, so that ambiguities during the application of the 3QM-Framework could be exposed, discussed and documented in a timely manner. The results of the quality determination were subsequently consolidated and examined. If quality defects were discovered which could not be allocated to any existing marks, this was taken as an indicator for an insufficient adequacy of the 3QM-Framework. Inconsistent allocations of quality defects to metrics and marks by the assessors were, furthermore, seen as an indicator for a reduced reliability of the 3QM-Framework. Consistent allocations of quality defects were instead rated as a confirmation.

At the end of the first design cycle, the 3QM-Framework was applied in a case study to evaluate 15 UML models as well as 15 BPMN models that each

Table 2 Rates of quality defects in the case study of the fourth design cycle (mean per model)

Quality metric	Original violation	Repeated violation	Original violation	Repeated violation	Original violation	Repeated violation
UML	2.00	2.75	0.75	1.00	1.08	0.61
EPC	0.78	1.49	1.95	1.68	0.46	0.03
Norm. Lang.	8.89	26.81	1.25	22.92	1.11	0.67
Quality mark	Word syntax		Sentence-level syntax		Text syntax	
	Syntactics					

Quality metric	Incorrect flow condition	Incorrect activity	Incorrect data flow	Incorrect event	Incorrect data object	Incorrect data object state	Incorrect control flow	Incorrect organizational unit	Superfluous flow condition	Superfluous activity	Superfluous data flow	Superfluous event	Superfluous data object	Superfluous data object state	Superfluous control flow	Superfluous organizational unit
UML	0.06	1.28	2.11	0.39	1.89	0.06	2.31	2.14	0.39	3.42	0.00	0.64	5.00	0.56	0.00	0.00
EPC	0.00	0.59	0.03	0.51	1.05	0.00	0.86	0.14	0.00	3.86	0.00	3.49	2.81	0.00	0.00	0.35
Norm. Lang.	0.39	2.25	0.00	0.03	1.50	0.56	2.17	0.19	0.86	10.11	0.00	0.39	2.03	0.00	0.00	0.00
Quality mark	Correctness								Relevance							
	Semantics															

Quality metric	Missing flow condition	Missing activity	Missing data flow	Missing event	Missing data object	Missing data object state	Missing control flow	Missing organizational unit	Constraints	Redundancy	Contradiction	Inconsistent label	Non-normalized label
UML	1.81	1.33	0.69	2.11	7.69	0.39	2.17	4.39	0.97	0.53	2.69	0.97	9.14
EPC	0.62	3.08	1.41	2.97	13.86	0.00	2.35	4.54	4.68	2.30	0.00	3.35	9.68
Norm. Lang.	5.08	6.53	0.67	0.83	11.75	0.00	9.78	0.36	7.78	1.53	0.19	13.36	3.50
Quality mark	Completeness								Flexibility	Unambiguity		Understandability	
	Semantics									**Pragmatics**			

had 72 model elements (not counting edges). An advanced version of the 3QM-Framework was used at the end of the second design cycle for the evaluation of respectively 15 UML and BPMN models of similar complexity (Birkmeier et al. 2010). At the end of the last design cycle, the usefulness of the 3QM-Framework was examined again during a case study with 36 UML and 37 EPC models, consisting of 73 and 134 model elements respectively, as well as 36 process descriptions in normative language (Overhage et al. 2011, 2012).

The results of the case studies show that many of the marks and metrics were readily usable beginning from the first version of the 3QM-Framework. Based on the study results, however, there also arose the need to further increase the usefulness of the 3QM-Framework through the addition, modification and removal of individual marks and metrics. For example, within the first version of the 3QM-Framework only violations against the rules of the modeling notation (syntactics) and content-related defects regarding the representation of the real world excerpt (semantics) were differentiated. To further be able to measure the interpretability of a business process model through the user, the framework was subsequently extended with pragmatics as a mark of its own and corresponding metrics. Besides, additional carriers of meaning were added in order to be able to assess the semantics of business processes in greater detail. While initially only activities, data objects and control flows were considered, data flows, flow conditions, organizational units, events and data object states were successively included.

Furthermore, certain metrics that handicapped a reliable allocation of quality defects and, hence, compromised the reliability of the framework were removed. For example, it can be observed that modelers occasionally speculate about parts of processes within other organizational units or enterprises which are not exactly known to the modeler. Therefore, the 3QM-Framework initially provided the metric fictive workflows that counted process parts in the models which are not part of the real world excerpt to be represented. However, the framework also provides the metric superfluous activities. Initially, this metric accounted for activities that were part of the real world excerpt to be represented, but were categorized as irrelevant because of their granularity. The executed studies showed that the two metrics cannot be separated accurately. Therefore, the corresponding quality defects are now homogeneously measured by the metrics of the relevance mark, whose definition has been modified accordingly.

The results of the last case study show that the assessors had no longer difficulties with the allocation of quality defects (**Table 2**) during the evaluation of the examined business process models. Besides, no additional sub-marks for the categories syntactics, semantics, and pragmatics were further discussed. The results, hence, document the adequacy of the marks and metrics presented in this paper to measure existing quality defects in business process models. Moreover, deviating opinions upon how to classify quality defects in the 3QM-Framework were no longer observed during the study. The results, therefore, also reflect a high reliability of the presented marks and metrics. Overall, the usefulness of the 3QM-Framework for the quality determination of business process models has been confirmed within the case study.

During the executed case studies, it was observed, however, that the quality level of the different marks varies depending on the evaluated formats and notations (**Table 2**). For example, a comparison of the absolute means reveals that process descriptions in normative language contained a significantly higher number of violations of the word and sentence-level syntax. The question, in how far such observations allow inferences on the applicability of the individual modeling notations, is the subject of investigation in several research endeavors (Overhage et al. 2011, 2012). In any case, the study results show, however, that an analysis of correlations and causalities between the single quality marks and metrics cannot be done independently of the properties of the modeling notation.

5.2 Expert Agreement

To further document its adequacy, we additionally examined in an expert survey whether the marks and metrics of the 3QM-Framework identify relevant deficiencies in business process models[1]. During the survey, an independent assessment of the 3QM-Framework by means of a so-called expert consensus was aspired. An expert consensus shows the agreement of experts to a research result and, thus, serves as evidence for the external validity of the results (Moody 2005, pp. 266–267). The survey particularly focused on the adequacy of the quality marks for the quality determination of business process models. Besides, possible gaps in the quality marks and metrics should be identified.

The expert survey was executed in 2010, subsequent to the last design cycle. It consisted of three steps. At first, demographic data and previous knowledge on the quality determination of models were collected. After this, the participating experts were provided with the definitions of the quality marks of the 3QM-Framework together with a visualization of typical quality defects. Based on these, all experts were asked for their opinion about the adequacy of each single

[1] Survey materials can be found in the online appendix.

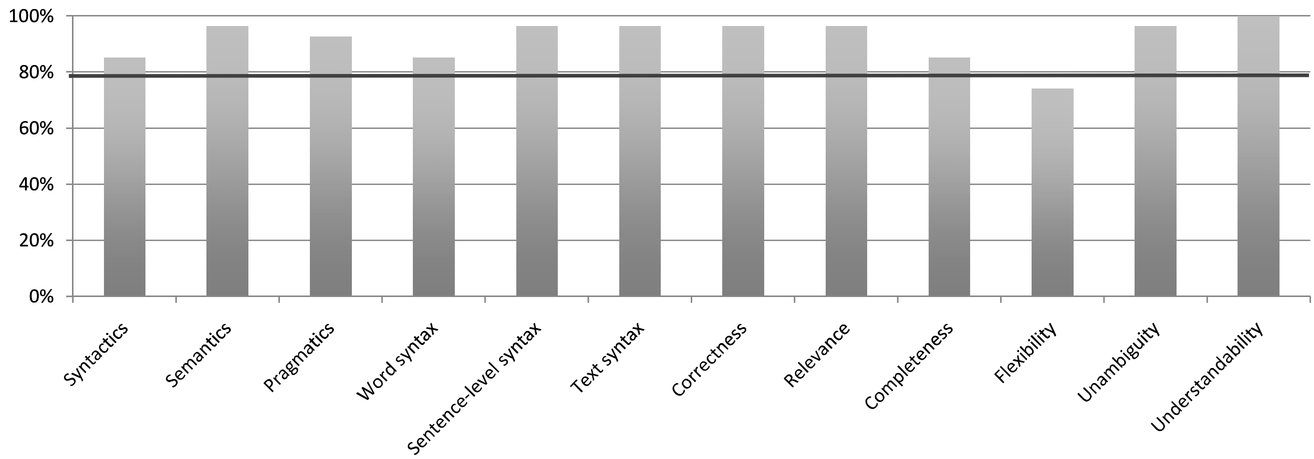


Fig. 6 Expert agreement to quality marks

mark and for possible improvement suggestions in the second step. In the third step, the quality metrics of the 3QM-Framework were explained and the experts were asked for possible improvements and amendments.

27 experts from research and practice participated in the survey. To achieve a consensus from experts, a minimum of two years of experience in business processes modeling was required as prerequisite for participation (Moody 2005, pp. 267–268). 75 % of the participating experts had more than five years of experience in process modeling, one third even more than ten years. Substantial experiences of the participants not only consisted in model creation (96 %), but also in model validation (85 %). On a 7-point Likert scale (from 1: "strongly nonfamiliar" – 7: "strongly familiar"), the experts rated their own experiences in quality assurance and validation of models with 5.78 on average. Overall, they maintained to know 5.52 different approaches for the quality determination of business process models.

Figure 6 shows the agreement of the experts to the quality marks of the 3QM-Framework that was measured on a yes/no scale. It varies between 100 % agreement to the understandability mark and 74.1 % agreement to the flexibility mark. The average agreement of the experts to the marks of the 3QM-Framework amounts to 91.7 %. Following Moody (2005, p. 267), an agreement of 80 % is considered as sufficient for the aspired expert consensus. The analysis of the survey results indicates a generally high acceptance of the 3QM-Framework. Especially does it confirm the relevance of the fundamental syntactics, semantics, and pragmatics marks. Concerning semantics and pragmatics, a high agreement of 96.3 % and 92.6 %, respectively, was measured. One reason for the slightly lower agreement of 85.2 % regarding syntactics could be the widespread tool support, which prevents violations against the lexicon and the grammar of the modeling notation. Nevertheless, a syntactically correct representation is also considered to be an overall important quality mark of a business process model. Hence, the sentence-level syntax and text syntax both obtained an agreement of around 96 % from the experts. Likewise, a high agreement was achieved by all sub-marks of the pragmatics.

With regard to the sub-marks of semantics, the agreement varied slightly more. The correctness, relevance, and completeness each achieved a high agreement. The agreement to the flexibility, on the other hand, was slightly below the critical value of 80 %. Based on the feedback, the reason for this could not be conclusively clarified. However, one possible acceptance barrier could be the deviating definitions of the flexibility term in literature, which might lead to a diverging relevance of the mark (Moody and Shanks 1994, p. 99). As the experts did not provide any alternative recommendations, the sub-mark was kept in the 3QM-Framework nonetheless.

During the survey, further extensions to the 3QM-Framework were suggested, which were afterwards examined with respect to their feasibility. On the one hand, it was proposed to additionally measure the perceived model quality (Sect. 2). However, this would lead to an inherent dependency of the quality determination on the appointed quality assessors and, hence, would reduce the reliability of the framework. On the other hand, the development of additional marks and metrics was suggested to enable an assessment of the quality of the graphical layout or the automation potential of business process models. The inclusion of marks and metrics for specific purposes, however, contradicts the aspired universal applicability of the 3QM-Framework. Therefore, none of the suggested extensions were realized at first. Yet, we aspire to develop application-specific quality profiles with additional marks and metrics which complement the 3QM-Framework. Based on these profiles, an evaluation of the quality of the graphical layout and the automation potential of process models shall be supported in the future.

5.3 Weighting Suggestion

With the weighted aggregation of individual quality measurements, the 3QM-Framework contains a method for the determination of the overall quality of a business process model. In doing so, the situational weighting of metrics and marks supports a quality determination which is adaptable to the respective project context (Moody and Shanks 1994, p. 100). Even though no fixed standard for the weighting is pursued, it can be reasonable to define a starting point for the weighting (Moody 2005, p. 268). In the context of the evaluation, we therefore examined in how far a weighting suggestion can be offered as an orientation for individual customizations.

Eleven experts who previously participated in the expert survey on the 3QM-Framework were involved in the deriva-

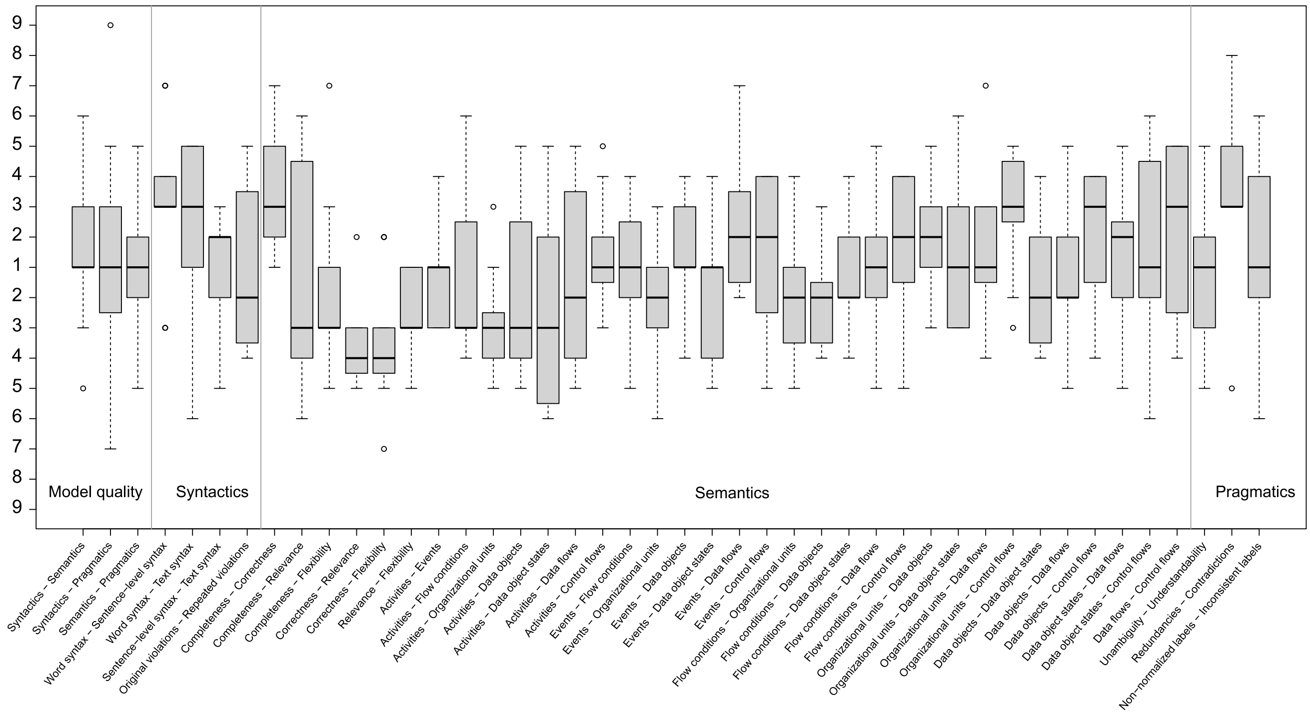


Fig. 7 Distribution of the evaluations of the significance of quality marks and metrics (boxplot)

tion of the weighting suggestion. Admittedly, the number of participants is not sufficient to derive a representative weighting. It does, however, enable us to examine if a unified weighting is at all possible and meaningful. According to the method defined in Sect. 4, each expert was therefore asked to perform a comparison of the significance of the marks and metrics based on his/her individual level of experience. For this, each expert was guided through the necessary pairwise comparisons with a stepwise questioning. The rating of the experts was documented and analyzed afterwards.

The analysis shows that the perceived significance of the quality marks and metrics in parts considerably differs between the participating experts (**Fig. 7**). The largest spread was observed during the comparison of the significance of syntactics and pragmatics, which ranges in an interval from −7 to +9. The smallest spread was observed during the comparison of the significance of word syntax and sentence-level syntax, where nine out of eleven experts assigned a preference in favor of the sentence-level syntax ([+3; +4]). The considerable spread in some comparisons shows that the significance of certain marks and metrics for the overall quality of a business process model is seen quite differently among the experts. Overall, the majority of the experts were, however, no more than two points away from each other in 50 % of the pairwise comparisons. Hence, the rating was also comparably stable for several pairwise comparisons. The small spread of the rating of these marks and metrics shows that homogeneous trends do exist among the experts that should be reflected in a weighting suggestion. For example, the experts viewed the usage of signs, which are not part of the lexicon, as having a rather low significance. It seems to be more important that improper direct and transitive combinations of signs are avoided. For the semantics marks likewise a high agreement in the ratings can be observed. In particular, the experts perceived the correctness of the carriers of meaning of a business process model as more important than superfluous or missing carriers of meaning.

On the one hand, the comparison results hence confirm that a weighting suggestion has to be situationally customized. On the other hand, general trends do exist which, apparently, are seen similar across the experts. During the analysis, we therefore calculated an average weighting based on the comparison results (**Fig. 8**). With 0 % to 2.8 %, the consistency ratios of the weighting suggestion range below the critical value of 10 %. Even though the weighting suggestion does not represent a universally valid standard for the quality determination, it can be used as a starting point for project-specific customizations.

5.4 Limitations

Several limitations have to be considered when interpreting the presented findings, as these might compromise the explanatory power of the evaluation results. For the time being, the presented reliability examination of the marks and metrics in Sect. 5.1 was based on a comparably low number of quality assessors in order to be able to observe their application of the 3QM-Framework as closely as possible. In so doing, only qualitative data on the reliability of the 3QM-Framework were gathered which cannot provide statistical evidence. To strengthen the external validity of the results with respect to the reliability of the 3QM-Framework, we will therefore have to increase the number of quality assessors in further studies. Moreover, quantitative data should be gathered in the future in order to attain statistically supported conclusions on the reliability of the 3QM-Framework. For a verification of the adequacy of the 3QM-Framework, however, business process models of industry partners from various sectors have already been used. Moreover, they have been represented in different modeling notations. Accordingly, the findings regarding the adequacy of the 3QM-Framework are already based

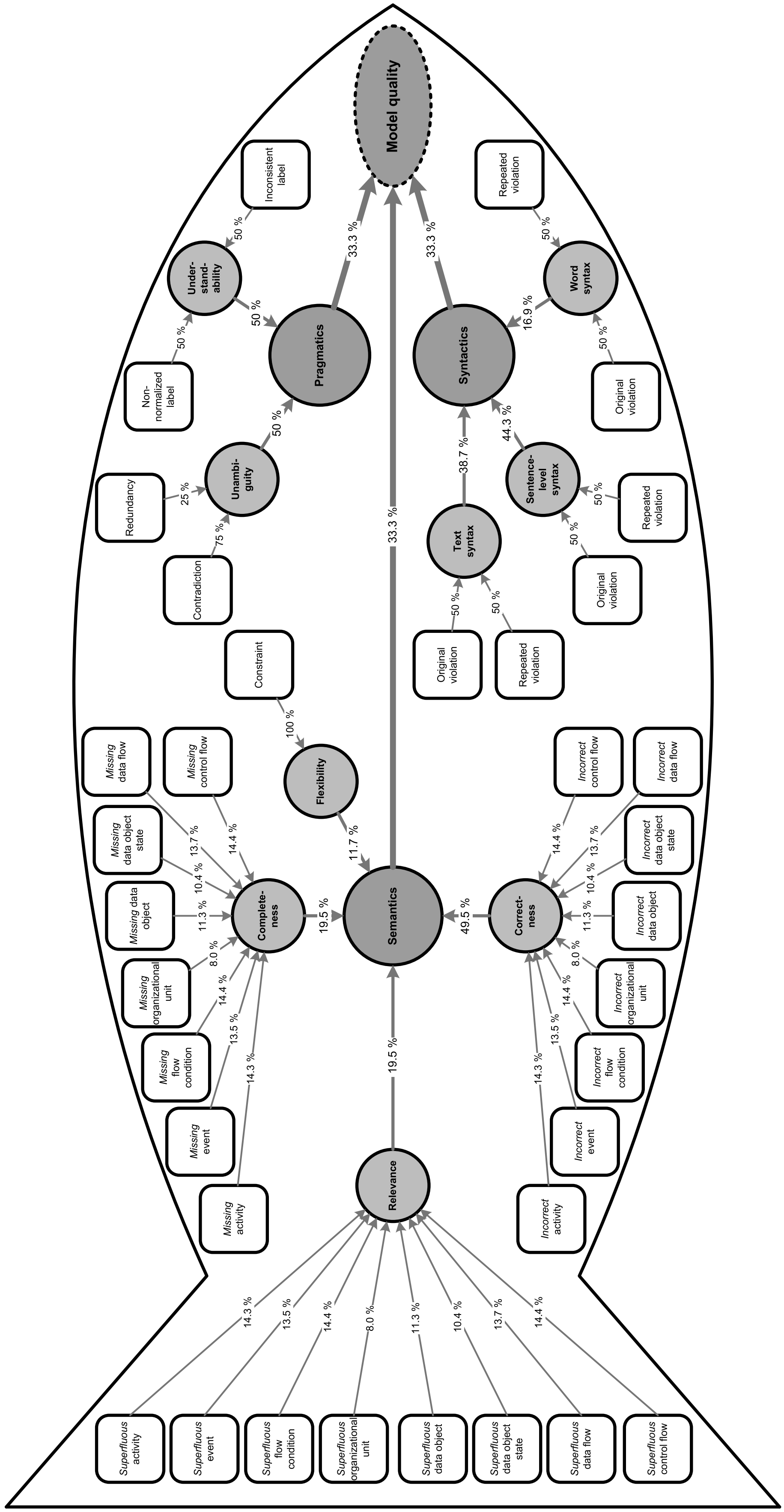


Fig. 8 Quality model of the 3QM-Framework with weighting suggestions

on comparably extensive data. Nevertheless, additional business process models should be assessed based on the 3QM-Framework to further increase the external validity of these results as well.

Finally, the number of consulted experts should be further increased in order to strengthen the validity of the conclusions regarding the expert consensus discussed in Sect. 5.2. Related to this, it also has to be considered to inquire into the expert agreement using a more detailed scale. With the yes/no scale that was used so far, it was only possible to examine the fundamental agreement of the experts. During the survey presented in Sect. 5.2, the experts were, however, encouraged to comment their rating if necessary. Furthermore, they were asked to suggest any extensions which might be necessary in their opinion. As both possibilities were only used sparsely during the survey, we consider the gained results on the fundamental expert agreement to be reliable.

6 Concluding Remarks

High-quality business process models are a central prerequisite for successful business process management. With the 3QM-Framework, we therefore presented an approach that supports the methodical quality determination of business process models. Taking semiotics as kernel theory, we identified fundamental quality marks which support an evaluation of the appropriateness of business process models as means of communication. Subsequently, we systematically refined the identified quality marks into a quality model (R3). Thereby, we defined concrete metrics and measurement procedures to measure the quality level of business process models (R4). The elements of the 3QM-Framework can be used independently from the notation that is employed for the modeling of business processes (R9). Moreover, the quality model supports the systematic weighting and aggregation of quality marks within a rational procedure (R5).

During the design of the quality model, we used the established structure of the ISO 9126 standard as a template (R1). In particular, we adopted the classification into quality marks, sub-marks, and metrics. Furthermore, we incorporated and consolidated existing related work on quality determination during the design (R2). For instance, the fundamental syntactics, semantics, and pragmatics quality marks correspond to the quality aspects of SEQUAL. The refinement of the semantics partially builds upon the GoM. When structuring the pragmatics, we incorporated quality criteria of the 7PMG that can be used independently of a specific notation format. We examined the adequacy and reliability of the 3QM-Framework in case studies, during which the quality of several business process models that were depicted in different notations was determined. The study results show that the 3QM-Framework enables the identification of practically relevant shortcomings in business process models and their unequivocal allocation to quality marks. Based on the suggestions from literature, we furthermore conducted an expert survey to confirm the structure of the quality model (R8).

Nevertheless, a variety of limitations have to be considered when assessing the 3QM-Framework. First of all, we have not included language-specific quality marks and metrics into the 3QM-Framework to ensure its aspired universal applicability. Besides the marks and metrics mentioned in the paper, there hence exist additional approaches which particularly support an examination of the pragmatics of graphically depicted business process models (Moody 2009, pp. 758–761). In order to be able to also take such language-specific approaches into account during the quality determination, we plan to extend the 3QM-Framework with so-called quality profiles that provide specific marks and metrics. Moreover, it has to be kept in mind that the 3QM-Framework only allows to assess the appropriateness of business process models as means of communications. Depending on the situational modeling scenario, additional requirements could arise, for example with respect to the automation potential, maintainability, and modifiability of business process models. In order to achieve a complete approach for quality determination, strategies to examine such requirements have also to be explored.

Besides the previously discussed fulfilled requirements, there finally exist additional ones which have not yet been implemented completely. Presently, we only provide a general statement about the target groups which have to be consulted during the determination of quality marks (R6). Furthermore, we do not provide quality assurance measures that are to be implemented if deficiencies are discovered (R7). Confirmed statements about the target groups which need to be incorporated and effective quality assurance measures can only be provided based on dedicated case studies in which the application of the 3QM-Framework is observed in practice. Based on the results of such studies, it is possible to analyze correlations and causalities that possibly also exist between the marks of the quality model. The execution of such case studies therefore belongs to the future research tasks as does the derivation of additional weighting suggestions that have been successfully used in different process modeling scenarios.

Despite these limitations, the gained insights are of relevance for academia and practice. For practice, we provide an approach that supports a methodical determination of the quality of business process models. The quality marks contained in the quality model provide an overview of the aspects which have to be examined during the quality determination. The provided metrics and measurement procedures moreover enable the unequivocal quantification of these quality marks, so that the quality analysis no longer has to be carried out in an ad-hoc fashion and based on the situational knowledge of the involved parties. As regards academia, the presented approach contributes to closing the research gap that exists with respect to analytical quality assurance approaches in the business process modeling domain.

Like SEQUAL, the 3QM-Framework is based on semiotics as kernel theory. However, SEQUAL uses the semiotic kernel theory especially to explain the interactions that exist between syntactics, semantics, and pragmatics as quality aspects. Furthermore, it explains the influencing factors that affect these quality aspects as determinants. While SEQUAL hence focuses on examining quality contexts on a large scale, the 3QM-Framework complementarily discusses quality contexts on the small scale. In the 3QM-Framework, the semiotic kernel theory is used to identify relevant quality marks and to complement them with suitable metrics and measurement procedures. Apart from the previously discussed further developments, future research could also strive for a combination of the two complementary approaches. We hope that the 3QM-Framework presented in this paper can thus provide a starting point for the development of holistic solutions to support the quality determination of business process models.

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Abstract

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Quality Marks, Metrics, and Measurement Procedures for Business Process Models

The 3QM-Framework

The availability of high-quality business process models is a central prerequisite for a successful process management. Nevertheless, in practice process models exhibit a large number of quality deficits, among them grammatical, content-related, and stylistic defects. In addition, there exist only very few approaches to determine the quality of business process models. In this paper, we present the 3QM-Framework, an analytical approach to systematically determine the quality of business process models. The 3QM-Framework makes three contributions: it provides quality marks, metrics, and measurement procedures to quantify the quality level as elements of a theoretically justified quality model. The applicability of the 3QM-Framework has been empirically evaluated in case studies. The results of a survey that was conducted among experts moreover attest its practical relevance.

Keywords: Business process modeling, Quality model, Quality marks, Metrics, Measurement procedures, Design science

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