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BUSINESS PROCESS MODEL QUALITY – RESULTS FROM A STRUCTURED LITERATURE REVIEW

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Research paper

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Abstract

Business process models are, among other things, used for documentation, reorganization and standardization purposes. However, no agreement on the quality dimensions relevant for business process models could be reached so far. In this paper, we try to contribute to the terminological discussion about business process model quality and aim to identify basic quality properties. For this reason, we examine how quality can be assessed depending on the intended purpose of the business process model. The resulting list of application scenarios is based on a structured literature review of 128 publications. The investigation shows that understandability and semantic quality are most frequently mentioned for several intended purposes of business process models. Our results can be considered as useful for research, since 'business process model quality' is linked to the intended purpose of business process models for the first time. In addition, the state of the art of the connections between quality dimensions of business process models is depicted.

Keywords: Business Process Modeling, Model Quality, Structured Literature Review.

1 Introduction

The increasing importance of business process modeling and management cannot be denied (Smirnov et al., 2012). Business process models are among other things used for the configuration of information systems, documentation purposes, reorganization of companies and the simulation, standardization and automatization of business processes (Bandara and Gable, 2012; Van der Aalst et al., 2003; Mendling and Recker, 2010). Not only has there been interest in generating new and changing existing process models, but also in evaluating their quality (Indulska et al., 2009; Lohrmann and Reichert, 2015). It is well known that the term "quality" can hardly be defined with general validity. We equate quality with the term 'suitability for use', which means that quality and the intended purpose of the business process model act in a coherent manner. Hence, to assess or evaluate quality, the assessors judging the quality (novices or experts in process modeling) as well as the intended purpose of the process model, need to be considered. Otherwise the same model can be understood in various ways, depending on who is evaluating it and for which purpose it is intended. A model that is experienced as high-quality by managers, may not be experienced in the same way by computer scientists. The same applies for models which are used for different purposes. Therefore, it is possible that a model intended for standardization purposes may have different quality requirements than a model intended for an information system implementation. In view of the multitude of different quality requirements for business process models, it becomes more than challenging to choose adequate ones. Despite the practical relevance of this topic, the empirical validation of the research efforts is rather poor. In addition, there is a lack of transparency on the basis of particular results. Therefore, especially in preparation for further research, a need for consolidation and examination of contradictions arises. Consequently, the contribution of this paper is threefold:

- Contribution to the terminological discussion of business process model quality and identification of basic quality properties
- Structured documentation and overview of business process model quality
- Impact of the factors according the intended use of the business process models, resulting in a list of application scenarios linked to the relevant quality factors

The remaining part of this paper is structured as follows: the second section gives an overview of related work, which attempts to assess the term quality in the context of business process models. Our research approach, the literature review process and the selection of relevant literature, follows in the third section. The fourth section describes our findings and provides answers to our research questions. The last chapter finishes with characteristic findings, the limitations of the study and with an outlook on possible future research.

2 Related Work

To the best of the authors' knowledge, a structured literature review on business process model quality and the intended purpose of use for business process models has not been published yet. However, a systematic literature review on the topic of business process modeling, a different level of business process management, has been conducted (Moreno Montes de Oca et al., 2015). Since no theories, neither empirical, normative nor formal ones, have developed so far, the literature was arranged according to the research stream addressed.

The definition of the concept of 'business process model quality' and the development of frameworks were one of the first efforts made. Model quality research from adjacent subfields, such as data and conceptual modeling served as a basis (Nelson et al., 2012; Moody, 2003). One of the first frameworks was introduced in 1994 (Lindland et al., 1994). The framework described different approaches to quality, such as syntactic, semantic and pragmatic quality. What followed were several adoptions of the

framework, the SEQUAL, the SIQ and the QoMO framework (Mendling and Recker, 2010; Krogstie et al., 1995; Van Bommel, 2007). The SEQUAL framework, for example, addresses further levels, such as social, language and knowledge quality (Krogstie et al., 1995). The SIQ framework extends previous works by addressing factors linked to the modeling and application process of process modeling (Mendling and Recker, 2010). The QoMO framework adds further goals in order to address business process model quality, for instance usage goals, creation goals and interpretation goals (Van der Aalst et al., 2007).

In addition to the frameworks, there are publications addressing the quality measurement of business process models, by selecting one or two dimensions. The term 'dimension' will be used in the following as a synonym for 'approach to quality', 'level', 'factor' and 'goal'. Mendling and Strembeck, for instance, investigate how textual content influences the understandability of business process models and whether there is a difference in perceived understandability for different modeling languages (Mendling and Strembeck, 2008). Recker and Dreiling investigate, whether the content presentation form and the user characteristics of the developers working with the business process models influences the understandability (Recker and Dreiling, 2011). Others try to use quality metrics and characteristics from different adjacent subfields in order to measure business process model quality. Gucegliogiu and Demirors, for example, try to apply Software quality characteristics, such as functionality, reliability, usability and maintainability, to business process models (Gucegliogiu and Demirors, 2005). Falge et al. try to combine data quality dimensions with business process models and therefore inter alia investigate accuracy, business rule conformity, completeness, consistency (Falge et al., 2012). In addition, first tools have also been developed, in order to assess business process model quality automatically. Van der Aalst et al. have developed a tool called ProM, which can be used for business process model and log-based analysis. They concentrate on the development of measurement criteria for non-perception based quality dimensions, for instance, 'Syntactic Quality' (Van der Aalst et al., 2007).

Based on this knowledge, initial approaches to provide instructions how a 'good' business process model should look like have been developed. Rosemann et al. conduct a case study to evaluate six guidelines for business process model quality: Semantic and Syntactic Correctness, Economic Efficiency, Clarity, Comparability and Systematic Design (Rosemann et al., 2001). One frequently cited approach, are the 'Seven process modeling guidelines (7PMG)' by Mendling et al. They describe that models should, for instance, only contain one start, and one end event, they should not include more than 50 elements and should use verb-object activity labels (Mendling et al., 2010). The 'Guidelines of Modeling' by Becker concentrate on diverse quality dimensions such as correctness, comparability and relevance and discuss how those can be obtained (Becker, 2000).

Others try to combine empirically confirmed theories with business process model quality. Houy et al. give an overview about theories such as the 'Cognitive Fit Theory' and the 'Technology Acceptance Model', which have been applied in the context of business process models (Houy et al., 2014). Figl et al. apply psychological theories in order to examine the cognitive effectiveness of routing symbols (Figl, 2017).

Insights such as the above-mentioned are important, but lack one comprehensive view on relevant quality dimensions of business process models. Since quality assurance of business process models has become an important factor for business process management at an enterprise level, the companies need to know which quality dimensions to assess, depending on their goals they want to obtain. As there is a missing structure within this field of research and scarce empirical verification, there are also scarce recommendations for actions. Even if first empirical verifications have been conducted (Mendling et al., 2006), they mostly consider only one dimension of quality. What is missing, however, is a literature review integrating all current insights into a comprehensive view on business process model quality so that the foundation for further investigations and correlating aspects can be laid. We see a need in not only defining relevant business process model qualities, but also in analyzing all the existing approaches together. At the end we should be able to reach a consensus that can provide a complete overview of the concept of business process model quality aligned with the purpose of the

model. Moreover, the development of a framework linking the intended purposes of process models and the therefore relevant quality dimensions could be an important step, in order to support companies with quality assessment of their business process models.

3 Literature Review

The literature search was divided into two parts and concentrated on the collection and evaluation of secondary literature, this means literature and data already published. Since we put our focus on a literature review, a primary data collection, in terms of self-gathered data, was not conducted. We therefore followed the approach for structured literature reviews by Webster and Watson (2002) and Vom Brocke et al. (2009). Figure 1 depicts the steps of the literature search process.

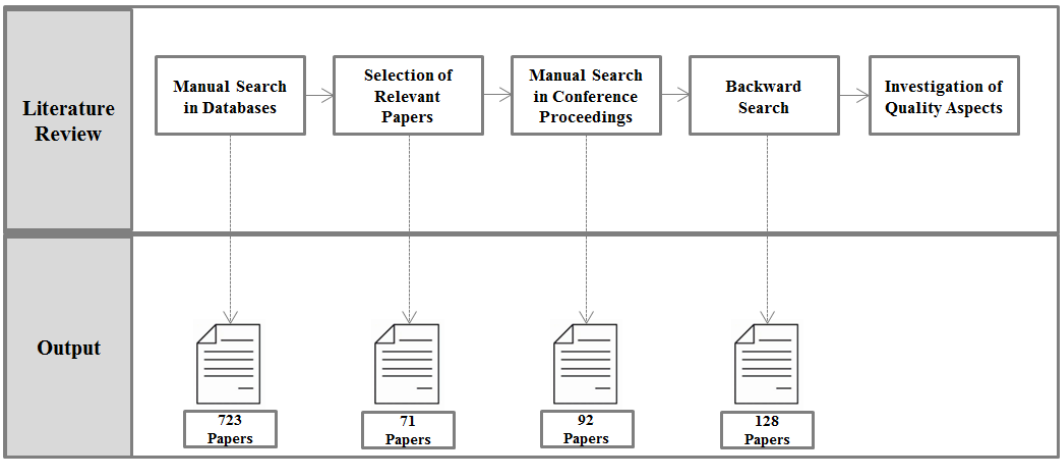

Figure 1. Literature Search and Selection Process.

The descriptors we have used for our search are the following:

((“business” AND “process” AND “model” AND “quality”) OR (“process” AND “model” AND “quality”) OR (“business” AND “process” AND “modeling” AND “quality”) OR (“business” AND “process” AND “modelling” AND “quality”) OR (“process” AND “modeling” AND “quality”) (“process” AND “modelling” AND “quality”) OR (“conceptual” AND “model” AND “quality”))

First we started by using the search databases GoogleScholar, Microsoft Academic, EconLit and Business Source Premier available at EBSCOhost. During the process we found 723 publications. After these have been evaluated by examining the title, abstract and the keywords, 71 papers were identified as relevant. In addition, we manually searched through all proceedings of the Business Process Management Conference, the European Conference on Information Systems, the International Conference on Information Systems, the International Conference on Advanced Information Systems Engineering and the International Conference on Conceptual Modeling, even though conference proceedings were already found within the database search. A first search within specific journals, as suggested by Vom Brocke et al., was considered unsuitable, since the area of research is too wide and publications are widely dispersed (Vom Brocke et al., 2009). Within the Conference Proceedings we could further identify 21 papers. Those were also chosen by looking at title, abstract and keywords. We made sure to only include papers, which had not been found by the manual search in the databases before. As a third step, we conducted a backward search and looked at literature which was referenced in the 92 papers found so far. That way we could determine further 36 papers dealing with aspects of business process model quality. Since no new quality dimensions arose within the 21 conference publications,

nor within the 36 publications from our backward search, we decided that we reached a saturation point. It is for this reason, we examined 128 publications that address the quality aspects. We included journal articles, conference papers and research articles published in books and on webpages. The illustration below shows however, that no publications before 1994 were found, and that most were found in 2007, with 14 publications in total. Another peak was in 2011 with 12 found publications.

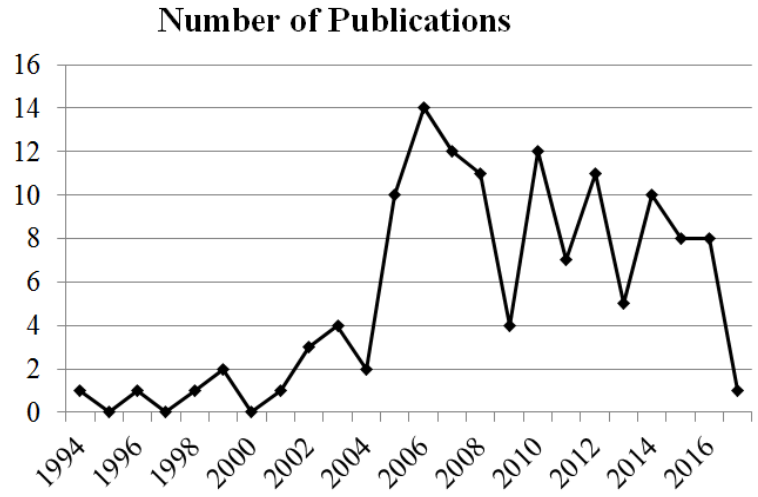

Figure 2. Number of publications per year.

We tried to select and investigate the literature by using the concept-centric approach (Webster and Watson, 2002). Since we wanted to compare the quality dimensions, we had to categorize the literature by concepts, or respectively superordinate quality dimensions, not authors. Therefore, we adapted a bottom-up approach, by first listing all quality dimensions mentioned and second assigning them to the concepts in the concept matrix. The concepts of the concept matrix were derived from 24 publications (printed in bold in the Appendix table 2) describing interdependencies and different levels of quality dimensions. Besides that, we also found publications addressing quality aspects which did not correspond to the quality dimensions of the 24 publications. Those publications dealt with aspects of automatization and mining for example and did not incorporate a business process model. Those publications were not included in our consideration. The same applied to all publications which, although dealing with business process management topics, did not consider business process models in the first place. Contributions on business process modeling quality were excluded, since they concentrate on the process of modeling, not the evolving product. Publications exclusively dealing with business process quality were excluded as well, since business process quality can be assessed without an underlying model.

4 Identification of Top Level Quality Dimensions

In this section, we provide a summary of the data collected from the 128 papers. A detailed account of the data can be found in the Appendix. To reduce the subjective bias, two people holding an Information Systems degree and giving lectures in business process management, have independently inspected of one another at the terms mentioned in combination with business process model quality. We afterwards compared our analyses and discussed about the quality dimensions evolved. Most authors mentioned Understandability (59%) and Semantic Quality (45%) in conjunction with business process model quality. Since some publications were only concentrating on one quality dimension and no interdependencies, we had to derive an approach for the arrangement and classification of the quality dimensions. As 24 publications from those found were describing interdependencies, different levels of quality dimensions and frameworks, we used those in order to separate first-level quality dimen-

sions and second-level quality dimensions. From those 24 publications we found 44 different quality dimensions which were initially transmitted unmodified. Second, we tried to build clusters bottom-up, concentrating on the hierarchy the 24 publications already described. Quality dimensions mentioned which were not included within those of the 24 publications, were added to a separate column 'Others' (see Appendix table 2). Since the authors from those 24 publications agreed that 'Semantic Quality' was of higher hierarchy than 'Correctness', for instance, we built our clusters as proposed in these publications. First-level quality dimensions, for instance 'Pragmatic Quality', contain a high level of abstraction and therefore need to be specified by more distinct second-level quality dimensions, for instance 'Unambiguity'. Even though the authors agreed on the definition of 'business process model quality' in general, no conformity about the quality dimensions relevant for business process model quality could be derived. Furthermore, even though the authors of the 24 publications agreed on the distinction between first-level and second-level quality dimensions, they disagreed over the amount of relevant quality dimensions. Besides, they also disagreed over the single assignment of second-level dimensions to first-level dimensions. This becomes apparent through the multiple assignments of second-level dimensions to first-level dimensions. 'Completeness' for instance, is assigned to 'Pragmatic Quality' but also 'Maintainability', since different authors have different opinions. This state is depicted in figure 3, in which 32 second-level dimensions are linked to 12 first-level dimensions. The figure shows a snapshot of all relevant quality dimensions mentioned within those 24 publications describing interdependencies and different quality levels as well as their sub-levels and linkages among each other.

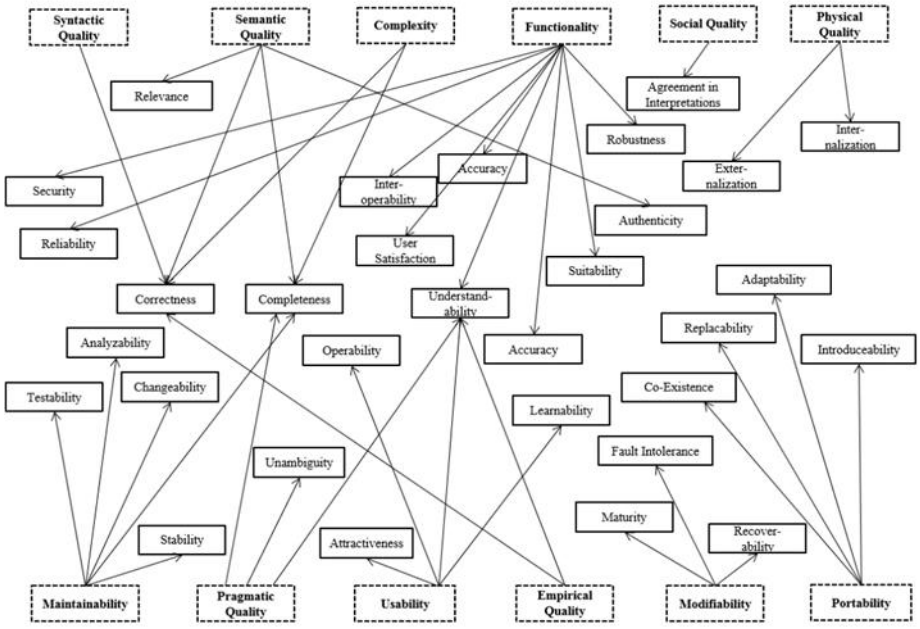

Figure 3. Quality Dimensions of Business Process Models and Interdependencies.

The overall results have not yet been quality assured, however it is aspired to do so in future. Moreover, at this point of time no statement about the interconnection between first-level and second-level quality dimensions can be made. It remains unclear, whether the interconnections are built formatively or reflectively. In order to learn more about the relevant quality dimensions for business process model quality and to focus on further research concerning the linkages among these, it was necessary to first depict the current state of the art in literature. It can be noted that more quality dimensions seem to contribute to a common understanding of business process model quality, however further investigations are needed in order to determine the dimensions' relevance.

4.1 Comparison of the Studies based on the Q-Dimensions

The first-level dimensions identified above are characterized as following. Syntactic Quality describes the correctness of the model structure and the suggested use of the modeling objects. Semantic Quality is understood as the interpretation of the model depiction in comparison to the business knowledge (Nysetvold and Krogstie, 2006). Pragmatic Quality describes the difference between the model and its interpretation. Social Quality describes the interpretation agreement of the people evaluating the process model. Physical quality describes both the availability of the model in the enterprise and the use of a modeling language in order to depict a process. Empirical quality deals with human computer interaction and describes inter alia the effects of foreground/background differences and workplace design (Nysetvold and Krogstie, 2006). Modifiability and Maintainability describe the simple alteration of process models in order to improve or reengineer them. Portability describes the model import and export between different tools, for example. Usability addresses attractive looking process models, Functionality deals with aspects such as security and interoperability of process models and Complexity is interrelated with completeness and correctness. Since a clear allocation of sub-level to first level dimensions was not always possible, there are sub-levels such as Completeness or Understandability, which seem to be important for more than one quality dimension. Hence it appears that there are sub-level quality dimensions which need to be regarded from different points of view and that authors do not always have the same perception of the quality dimension, when, for instance, they mention Understandability. However, it has not been investigated yet, whether the multiple assignments are reasonable and whether the interdependencies make the concerned quality dimensions influence each other. In regards to the evaluation in the Appendix, it needs to be mentioned that quality dimensions, such as Understandability or Completeness, have been allocated to their superior dimensions. Ambiguous sub-levels, which could not be clearly assigned on basis of the context, were assigned to all according first-level quality dimensions. The dimension 'Others' can be applied to those publications, whose description of quality models is so specific that it does not fit into one of the common dimensions. This refers to Mendling et al. (2010) for example who describe ISO 9001 quality oriented process models and Rosemann (2006) who concentrates on the quality of special procurement processes, within a unique context.

4.2 Relevance of Quality Dimensions for Business Process Model Use Scenarios

The first-level quality dimensions mentioned before were applied again, in order to compare them to the intended purposes of business process models mentioned in the publications. It needs to be pointed out that 21 publications did not mention any purposes at all. The remaining authors mentioned at least one intended purposes of business process models, in most instances even more. Several authors aimed to gain insight into BPM research (Nagm-Aldeen et al., 2015; Aldin and De Cesare, 2011; Aguilar-Saven, 2004). We have concentrated on Sidorova's and Isik's business process research review in order to sort and categorize the intended purpose of business process models (Sidorova and Isik, 2010). Sidorova and Isik describe 20 different areas of business process research, of which 10 areas were named in relation to business process model quality research. We looked through all text passages of the publications in search of a mentioned intended purpose. The mentioned purposes found in business process model quality literature were first written down in their initial wording. Afterwards, we looked at the relatedness of the intended purposes and built clusters bottom-up and, if possible, assigned those to the areas identified by Sidorova and Isik. Intended purposes found but not named by Sidorova and Isik were clustered in 'Others'. This applies for the validation of EPC models, the creation of reference models and the comparison of business processes. Table 1 shows the purposes identified with an assignment to the quality dimension they address.

Intended Purpose	Syntactic Q.	Semantic Q.	Pragmatic Q.	Social Q.	Physical Q.	Empirical Q.	Complexity	Functionality	Modifiability	Portability	Usability	Maintainability	Others	**Count**
ERP	x	x	x	x	x	x	x		x		x	x	x	**54**
Organizational implementation of BP initiatives	x	x	x	x	x	x	x	x	x	x	x	x	x	**44**
Simulation and BP optimization methods	x	x	x	x	x	x	x	x	x	x	x	x	x	**27**
No intended purpose	x	x	x				x							**22**
BP re-engineering	x	x	x			x	x	x	x			x	x	**16**
Others	x	x	x	x									x	**13**
Performance Measurement	x	x	x			x	x	x	x		x	x	x	**11**
BP outsourcing	x	x	x					x					x	**7**
Workflow management	x	x	x										x	**6**
KM and innovation	x	x	x	x	x	x							x	**4**
Web Services and SOA			x				x					x		**2**
Auditing		x											x	**3**

Table 1. Quality Dimensions and Intended Purposes.

It is interesting to note that some purposes which were expected to be named, since they are decisive for Business Process Management projects, were omitted in all of the 128 publications. This is the case for 'Standardization'. Furthermore, there are intended purposes such as 'ERP' and 'Documentation', assigned to 'Organizational implementation of BP initiatives', which seem to be relevant for several quality dimensions. Besides, quality dimensions such as 'Physical Quality' are linked to the 'Development of Information Systems' in the first place but have not been tested empirically, since the information is mainly gathered from frameworks. Moreover, it can be stated that 10 out of 20 of Sidorova's and Isik's areas were not mentioned at all: marketing and CRM, SCM, TQM, institutional issues in BP research, E-Commerce, BP in the public sector, Six Sigma, HR, BPR and manufacturing.

5 Discussion and Conclusion

In this paper we have addressed the understanding of quality in terms of business process models. We conducted a systematic literature review and consolidated 121 publications. We identified 12 quality dimensions and 32 different sub-criteria for the assessment of business process model quality. Among these studies, almost every second paper (45%) deals with Semantic Quality, Understandability is addressed even more often (59%). The less popular quality dimensions were solely mentioned within the development of new frameworks and theories, or conducted literature reviews. We found that the research rather concentrated on Syntactic, Semantic and Pragmatic Quality or that the quality derived from software development or data management. A combination of two approaches was rare. Furthermore, it is worth emphasizing that even though the authors have close perceptions of the term 'business process model quality', they have different opinions on the relevant quality dimensions. For example, some authors compare the quality with the size of the process model.

5.1 Limitations of the Study

The literature review conducted in this paper has some limitations. Firstly, our results can be expanded by carrying out a systematic and automatic search. Secondly, we only searched within four databases and the Proceedings of the Business Process Management Conference, the European Conference on Information Systems, the International Conference on Information Systems, the International Conference on Advanced Information Systems Engineering and the International Conference on Conceptual

Modeling. Future research could include further research databases and further conference proceedings. Apart from that, we mainly focused on the descriptors '(Business) Process Model Quality', '(Business) Process Mode(l)ling Quality' and 'Conceptual Model Quality'. In order to gain further insight, the search can be extended by using descriptors concentrating on the single quality dimensions. Moreover, the assignment of the quality dimensions and the intended purposes of the business process models was conducted subjectively, so that a further verification is necessary, for example via Delphi study. The allocation of first-level and second-level quality dimensions was independently conducted by two scholars, however the results need to be further investigated and quality assured.

5.2 Implications and Opportunities for further research

We do not consider this study to be the end of the investigation process. To begin with, the interrelations between the different quality dimensions need to be examined and empirically investigated, in order to find out whether and how they influence each other. Firstly, third-level measurement criteria for selected quality dimensions, such as Semantic and Pragmatic Quality, have been developed but not empirically tested. Secondly, there have not been investigations for comparing different modeling languages. Experiments and interviews are conducted within one group, for example modeling novices, experts or students while the insights are not compared. Not all quality dimensions are taken into consideration equally. Physical Quality or Portability, for example, are rarely discussed. Furthermore, the investigation of upstream and downstream task fields of Business Process Management needs to be considered. It would be interesting to understand the relationships between the quality of business process modeling, business process models and business processes. Moreover, new techniques could be applied in order to investigate specific quality dimensions. Semantic Quality for example, could be examined with procedures of text mining or analyzed by looking at cultural and linguistic differences. Finally, specific third-level measurement criteria and their order of importance could be derived and subsequently evaluated.

Author (s)	Title	Year	Author (s)	Title	Year	Author (s)	Title	Year	Author (s)	Title	Year
Agarwal et al.	Comprehending object and process models: An empirical study	1999	Dean et al.	Facilitation Methods for use with EMS Tools to Enable Rapid Development of High Quality Business Process Models	1996	Gucegliogl u & Demirors	**A Process Based Model for Measuring Process Quality Attributes**	2005	La Rosa et al.	Managing Process Model Complexity via Concrete Syntax Modifications	2011
Aranda et al.	A framework for empirical evaluation of model comprehensibility	2007	Dehnert & Zimmermann	On the suitability of correctness criteria for business process models	2005	Haisjackl et al.	**Identifying Quality Issues in BPMN Models: an Exploratory Study**	2015	Latva-Koivisto	Finding a complexity measure for business process models	2001
Armas-Cervantes et al.	Behavioral Comparison of Process Models Based on Canonically Reduced Event Structures	2014	De Oca et al.	A systematic literature review of studies on business process modeling quality	2015	Heggset et al.	**The Influence of Syntactic Quality of Enterprise Process Models on Model Comprehension**	2015	Leopold et al.	Supporting Process Model Validation through Natural Language Generation	2014
Azim & Cock	An experimental study of process representation approaches and their impact on perceived modeling quality and redesign success	2005	Dietzsch	"Ratios to Support the Exploration of Business Process Models"	2003	Heidari et al.	A Quality-Oriented Business Process Meta-Model	2011	Leopold et al.	Learning from Quality Issues of BPMN Models from Industry	2016
Aguilar et al.	**Evaluation of BPMN Models Quality - A Family of Experiments**	2008	Dongen & Jansen-Vullers	A Unified Approach for Measuring Precision and Generalization Based on Anti-alignments	2016	Heidari & Luocopoulos	Quality evaluation framework (QEF): Modeling and evaluating quality of business processes	2014	Leung & Bolloju	Analyzing the Quality of Domain Models Developed by Novice Systems Analysts	2005
Bandara & Gable	A Formative Measurement Model Of Business Process Model Quality	2012	Falge et al.	Data Quality Requirements of Collaborative Business Processes	2012	Heinrich & Paech	Defining the Quality of Business Processes	2010	Lincoln & Gal	Content-Based Validation of Business Process Modifications	2011
Becker et al.	Configurative Process Modeling - Outlining an Approach to increased Business Process Model Usability, Innovations through Information Technology	2004	Fernandez-Ropero et al.	**Quality-Driven Business Process Refactoring**	2012	Heravizadeh et al.	**Dimensions of Business Processes Quality (QoBP)**	2008	List & Korherr	An Evaluation of Conceptual Business Process Modelling Languages	2006
Becker & Klingner	Towards Customer-Individual Configurations of Business Process Models	2012	Fettke et al.	From Measuring the Quality of Labels in Process Models to a Discourse on Process Model Quality: A Case Study	2012	Holschke et al.	Granularity as a Cognitive Factor in the Effectiveness of Business Process Reuse	2009	Lohmann & Fahland	Where Did I Go Wrong? Explaining Errors in Business Process	2014
Brockmans et al.	**Semantic Alignment of Business Processes**	2006	Fettke & Loos	Ontological evaluation of reference models using the Bunge-Wand-Weber model	2003	Houy et al.	On the theoretical foundations of research into the understandability os business process models	2014	Maes & Poels	Evaluating quality of conceptual modelling scripts based on user perceptions	2007
Burton-Jones & Meso	How Good are These UML Diagrams? An Empirical Test of the Wand and Weber Good Decomposition Model	2002	Figl	**Comprehension of Procedural Visual Business Process Models**	2017	Johannsen et al.	Testing the Impact of Wand and Weber's Decom-position Model on Process Model Understandability	2014	Mendling	Testing Density as a Complexity Metric for EPCs	2006
Caballero et al.	IQM3: Information Quality Management Maturity Model	2008	Figl et al.	**The Influence of National Deficiencies on Process Model Comprehension**	2013	Khaluf et al.	Pattern-Based Modeling and Formalizing of Business Process Quality Constraints	2011	Mendling	Managing Structural and Textual Quality of Business Process Models	2012
Cardoso	**Evaluating the Process Control-flow Complexity Measure**	2005	Figl & Laue	Cognitive Complexity in Business Process Modeling	2011	Khaloun & Channouchi	Quality Criteria and Metrics for Business Process Models in Higher Education Domain: Case of Tracking of Curriculum Offers Process	2016	Mendling et al. 2007a	**Understanding the occurence of errors in process models based on metrics**	2007
Cardoso	Business Process Control-Flow Complexity: Metric, Evaluation, and Validation	2008	Foerster et al.	Activity Diagram Patterns for Modeling Quality Constraints in Business Processes	2005	Khlif et al.	Quality metrics for business process modeling	2009	Mendling et al. 2007b	What Makes Process Models Understandable?	2007
Cardoso et al.	**A discourse on complexity of Process Models**	2006	Foerster et al.	A Pattern-driven Development Process for Quality Standard-conforming Business Process Models	2006	Klinkmueller et al.	Listen to me: Improving Process Model Matching through User Feedback	2013	Mendling et al. 2010a	Seven process modeling guidelines (7PMG)	2010
Carpinetti et al.	Quality management and improvement: A framework and a business-process reference model	2003	Foerster et al.	Verification of Business Process Quality Constraints Based on Visual Process Patterns	2007	Klinkmmueller et al.	Increasing Recall of Process Model Matching by Improved Activity Label Matching	2013	Mendling et al. 2010b	On the Usage of Labels and Icons in Business Process Modeling	2010
Cherfi et al.	Improving Business Process Model Quality Using Domain Ontologies	2013	Gemino & Wand	A framework for empirical evaluation of conceptual modeling techniques	2004	Knuplesh et al.	On Enabling Compliance of Cross-organizational Business Processes	2013	Mendling & Reijers	The Impact of Activity Labeling Styles on Process Model Quality	2008
Claes et al.	Tying Process Model Quality to the Modeling Process: The Impact of Structuring, Movement, and Speed	2012	Ghani et al.	Complexity Metrics for Measuring the Understandability and Maintainability of Business Process Models using Goal-Question-Metric (GQM)	2008	Koehler et al.	Combining Quality Assurance and Model Transformations in Business-Driven Development	2008	Mendling & Strembeck	Influence Factors of Understanding Business Process Models	2008
Cortes-Cornax et al.	Evaluating Choreographies in BPMN 2.0 Using an Extended Quality Framework	2011	Gruhn & Laue 2006a	Complexity Metrics for Business Process Models	2006	Koepke & Su	Towards Quality-Aware Translations of Activity-Centric Processes to Guard Stage Milestone	2016	Moody et al.	Evaluating the Quality of Process Models: Empirical Testing of a Quality Framework	2002
Cruz-Lemus et al.	Assessing the understandability of UML statechart diagrams with composite states – A family of empirical studies	2009	Gruhn & Laue 2006b	Adopting the Cognitive Complexity Measure for Business Process Models	2006	Krogstie	**Quality of Business Process Models**	2012	Moreno-Montes de Oca et al.	A systematic literature review of studies on business process modeling quality	2015
Danesh & Kock	An experimental study of process representation approaches and their impact on perceived modeling quality and redesign success	2005	Gruhn & Laue	What business process modelers can learn from programmers	2007	Krogstie et al.	**Process models representing knowledge for action: a revised quality framework**	2006	Mrasek et al.	User-Friendly Property Specification and Process Verification – a Case Study with Vehicle-Commissioning Processes	2014
Dean et al.	**Modeling with a Group Modeling Tool: Group Support, Model Quality, and Validation**	1994	Gruhn & Laue	Detecting Common Errors in Event-Driven Process Chains by Label Analysis	2015	Laue & Mendling	Structeredness and ist significance for correctness of process models	2010	Nelson et al.	Quality in conceptual modeling: five examples of the state of the art	2005

Author (s)	Title	Year	Author (s)	Title	Year	Author (s)	Title	Year	Author (s)	Title	Year
Nelson & Monarchi	**Ensuring the quality of conceptual representations**	2007	Sadiq & Orlowska	Applying Graph Reduction Techniques for Identifying Structural Conflicts in Process Models	1999	Vanderfeesten et al.	On a Quest for Good Process Models: The Cross-Connectivity Metric	2008			
Nysetvold & Krogstie	Assessing Business Processing Modeling Languages Using a Generic Quality Framework	2006	Saeedi et al.	Extending BPMN for Supporting Customer-Facing Service Quality Requirements	2010	Van Dongen & Jansen-Vullers	Verification of SAP Reference Models	2005			
Ofner et al.	Integrating a data quality perspective into business process management	2012	Sanchez-Gonzalez et al. 2010a	Prediction of Business Process Model Quality based on Structural Metrics	2010	Wang et al.	A Feature Space-based Business Model Quality Evaluation Method	2008			
Overhage et al.	**QualityMarks,Metrics, and Measurement Procedures for Business Process Models**	2012	Sánchez-González et al. 2010b	Quality assessment of business process models based on thresholds	2010	Wohed et al.	On the Suitability of BPMN for Business Process Modelling	2006			
Pittke et al.	Context-Sensitive Textual Recommendations for Incomplete Process Model Elements	2015	Sanchez-Gonzalez et al.	**Quality Indicators for Business Process Models from a Gateway Complexity Perspective**	2012						
Polyvyanyy et al.	The Triconnected Abstraction of Process Models	2009	San Pedro & Carmona	Log-based simplification of process models	2015						
Recker	Towards an understanding of process model quality. Methodological considerations	2006	San Pedro & Cortadella	Discovering Duplicate Tasks in Transition Systems for the Simplification of Process Models	2016						
Recker	**A Socio-Pragmatic Constructionist Framework for Understanding Quality in Process Modelling**	2007	Schrepfer et al.	The Impact of Secondary Notation on Process Model Understanding	2009						
Recker et al.	How good is BPMN really? Insights from theory and practice	2006	Schuette & Rotthoew	The Guidelines of Modeling - An Approach to Enhance the Quality in Information Models	1998						
Recker et al.	The ontological deficiencies of process modeling in practice	2010	Shanks et al.	Representing Part-Whole Relations in Conceptual Modeling: An Empirical Investigation	2002						
Recker et al.	**Do Ontological Deficiencies in Modeling Grammars Matter?**	2011	Seok et al.	Development of Quality Evaluation Metrics for BPM (Business Process Management) System	2005						
Recker et al.	Process Model Comprehension: The Effects of Cognitive Abilities, Learning Style and Strategy	2014	Storch et al.	**Measuring and Visualising the Quality of Models**	2013						
Recker & Rosemann	**The measurement of perceived ontological deficiencies of conceptual modeling grammars**	2010	Tiwari et al.	Towards End-to-End Multi-dimensional Quality Evaluation of Business Processes	2014						
Reijers & Mendling	Modularity in Process Models: Review and Effects	2008	Thomas & Fellmann	Semantic Process Modeling – Design and Implementation of an Ontology-based Representation of Business Processes	2007						
Rinderle et al.	**Evaluation of Correctness Criteria for Dynamic Workflow Changes**	2003	Turetken et al.	The effect of Modularity Representation and Presentation Medium on the Understandability of Business Process Models in BPMN	2016						
Rittgen	Quality and Perceived Usefulness of Process Models	2010	Van der Aalst	Challenges in Business Process Analysis	2007						
Rogge-Solti et al.	In Log and Model We Trust? A Generalized Conformance Checking Framework	2016	Van der Aalst et al.	ProM 4.0: Comprehensive Support for Real Process Analysis	2007						
Rosemann 2006a	Potential pitfalls of process modeling: part A	2006	Van der Aa et al.	Detecting Inconsistencies between Process Models and Textual Descriptions	2015						
Rosemann 2006b	Potential pitfalls of process modeling: part B	2006	Van der Aa et al.	Dealing with Behavioral Ambiguity in Textual Process Descriptions	2016						
Russell et al.	On the Suitability of UML 2.0 Activity Diagrams for Business Process Modelling	2006	Vanderfeesten et al.	**Quality Metrics for Business Process Models**	2007						

Table 2. Overview of relevant Publications.

Authors	Syntactic Q.	Semantic Q.	Pragmatic Q.	Social Q.	Physical Q.	Empirical Q.	Complexity	Functionality	Modifiability	Portability	Usability	Maintainability	Others
Agarwal et al. (1999)			x										
Aranda et al. (2007)			x										
Armas-Cervantes et al. (2014)													x
Azim & Cock (2005)			x										
Aguilar et al. (2008)			x				x		x				
Bandara & Gable (2012)		x									x		
Becker et al. (2004)									x				x
Becker & Klingner (2012)			x										x
Brockmanns et al. (2006)		x											
Burton-Jones & Meso (2002)			x										
Caballero et al. (2008)		x											
Cardoso (2005)			x				x					x	
Cardoso (2008)			x				x					x	x
Cardoso et al. (2006)	x		x				x					x	
Carpinetti et al. (2003)			x	x									
Cherfi et al. (2013)	x	x											
Claes et al. (2012)	x		x										
Cortes-Cornax et al. (2011)	x	x	x										x
Cruz-Lemus et al. (2009)			x				x		x				
Danesh & Kock (2005)			x										
Dean et al. (1994)		x	x					x					
Dean et al. (1996)	x								x				
Dehnert & Zimmermann (2005)	x	x											
De Oca et al. (2015)	x	x	x			x	x		x			x	x
Dietzsch (2003)							x						x
Dongen & Jansen-Vullers (2005)	x	x											
Falge et al. (2012)		x						x					x
Foerster et al. (2005)													x
Foerster et al. (2006)													x
Foerster et al. (2007)													x
Gemino & Wand (2004)													
Ghani et al. (2008)	x		x										
Gruhn & Laue (2006a)			x										
Gruhn & Laue (2006b)		x	x										
Gruhn & Laue (2007)		x	x										
Gruhn & Laue (2015)	x		x									x	
Gucegliogl u & Demirors (2005)									x			x	x
Haisjackl et al. (2015)	x	x	x									x	
Heggset et al. (2015)	x	x	x										
Heidari et al. (2011)									x				
Heidari & Luocopoulos (2014)			x										x
Heinrich & Paech (2010)									x		x	x	x
Heravizadeh et al. (2008)			x						x			x	
Holschke et al. (2009)										x			x
Houy et al. (2014)			x										
Johannsen et. al (2014)			x										x
Khaluf et al. (2011)													x
Khaloun & Channouchi (2016)		x	x									x	
Khlif et al. (2009)													x
Klinkmüller et al. (2013)			x										
Klinkmüller et al. (2014)								x					
Knuplesch et al. (2013)			x										x
Koehler et al. (2008)	x	x											
Koepke & Su (2016)	x	x											
Leopold et al. (2016)	x	x	x										x
Leung & Bolloju (2005)	x	x	x										x
Lincoln & Gal (2011)		x											x
List & Korherr (2006)	x			x									
Lohmann & Fahland (2014)													x
Maes & Poels (2007)		x	x										x
Mendling (2006)													x
Mendling (2012)			x										x
Mendling et al. (2007a)			x	x									
Mendling et al. (2007b)			x										
Mendling et al. (2010a)	x												
Mendling et al. (2010b)		x	x										
Mendling & Reijers (2008)		x	x										
Mendling & Strembeck (2008)			x	x									
Moody et al. (2002)	x	x	x										
Moreno-Montes de Oca et al. (2015)	x	x	x										
Mrasek et al. (2014)	x												
Nelson et al. (2005)	x	x	x	x	x	x							
Nelson & Monarchi (2007)	x	x	x										x
Nysetvold & Krogstie (2006)	x	x	x	x	x	x							
Ofner et al. (2012)													x
Overhage et al. (2012)	x	x	x										
Pittke et al. (2015)		x											
Polyvyanyy et al. (2009)	x		x										
Recker (2006)	x	x	x										
Recker (2007)	x	x	x										
Recker et al. (2006)		x	x										
Rittgen (2010)	x	x	x	x									
Rogge-Solti et al. (2016)													x
Rosemann (2006a)													x
Rosemann (2006b)	x	x										x	
Russell et al. (2006)	x												
Sadiq & Orlowska (1999)	x						x						
Saeedi et al. (2010)													x
Sánchez-González et al. (2010a)			x						x				
Sánchez-González et al. (2010b)			x						x				
Sánchez-González et al. (2012)			x									x	
San Pedro & Carmona (2015)			x										
San Pedro & Cortadella (2016)			x										x
Schrepfer et al. (2009)			x										x
Schuette & Rotthowe (1998)	x	x	x										x
Shanks et al. (2002)			x										
Seok et al. (2005)									x		x	x	x
Storch et al. (2013)	x	x	x									x	x
Tiwari et al. (2014)		x											x
Thomas & Fellmann (2007)		x											
Turetken et al. (2016)			x										
Van der Aalst (2007)	x	x											
Van der Aalst et al. (2007)	x	x							x				x
Van der Aa et al. (2015)		x											
Van der Aa et al. (2016)		x	x										
Vanderfeesten et al. (2007)	x	x											x
Vanderfeesten et al. (2008)			x										x
Van Dongen & Jansen-Vullers (2005)	x	x											

Fernández-Ropero et al. (2012)			x						x				
Fettke et al. (2012)			x										
Fettke & Loos (2003)		x	x										
Figl (2017)			x										
Figl et al. (2013)		x	x										
Figl & Laue (2011)			x				x						

Krogstie (2012)	x	x	x	x	x	x							
Krogstie et al. (2006)	x	x	x	x	x	x							
Laue & Mendling (2010)		x	x										
La Rosa et al. (2011)	x		x										
Latva-Koivisto (2001)	x												x
Leopold et al. (2014)		x											

Recker et al. (2010)													x
Recker et al. (2011)		x	x										x
Recker et al. (2014)			x										
Recker & Rosemann (2010)		x	x										
Reijers & Mendling (2008)			x										
Rinderle et al. (2003)	x								x				

Wang et al. (2008)	x	x											x
Wohed et al. (2006)	x												x

Table 3. Analysis of Quality Dimensions.

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