Current Practice in Measuring the Quality of Conceptual Models: Challenges and Research

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Abstract: *How to measure the quality of conceptual models is an important issue in the IS field and related research. This paper conducts a review of research in measuring conceptual model quality and identifies the major theoretical and practical issues that need to be addressed in future studies. We review current classification frameworks for conceptual model quality and practice of measuring conceptual model quality. Based on the review, challenges for studies of measuring the quality of conceptual models are proposed and these challenges are also research points which should be strengthened in future studies.*

Key words: conceptual model quality; measurement; syntactic quality; semantic quality; pragmatic quality

1 Introduction

Whith the development of information systems, conceptual modeling is a key part of the early stages and can be defined as the process of documenting a specific problem domain in order to understand and communicate among stakeholders[1]. According to the theory of software engineering, conceptual models are used to develop, acquire or modify information systems and are central to IS analysis and design[2,3]. Conceptual modeling defines user requirements at three levels: application level, enterprise level and industry level. At different levels, the object supports varies in line with specific goals. Take military conceptual model as example; it is the first abstract to the military action world (space)[4], and its accuracy and rationality play important roles in the subsequent phases.

Conceptual model quality may affect IS development in two ways. First, high quality of a conceptual model can enhance the efficiency (time, cost, effort) of development dramatically. Previous studies show that requirements errors have accounted to more than 50% of the total errors during system development[5,6]. The cost of errors increases exponentially over the development lifecycle: it will lead to more than 100 times cost to correct an error in implementation than in requirement analysis[7]. This suggests that quality assurance efforts in the requirement analysis are economically beneficial. In addition, high quality of a conceptual model can bring effectiveness (quality of results) for IS development. Namely, a high quality conceptual model will result in a high quality information system and a poor quality conceptual model will lead to a system that does not satisfy users (as a consequence of not detecting or not correcting defects)[8].

The quality of IS, which is the final product of software development, has raised a lot of attention in the world and has many relatively mature research results. However, research related to conceptual model quality remain in a start-up condition. Currently, the practice of evaluating quality of conceptual models has more characteristics of an art than a precise scientific or engineering discipline. It is concluded that related research are lack of empirical testing, lack of agreement on concepts and terminology, lack of adoption in practice and lack of knowledge about current practice and so on[8]. All of these shortages reflect the immaturity of the research field.

On this background, the present paper reviews current practice in measuring the quality of a conceptual

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model and gives an empirical basis on discussing how to measure conceptual model quality. On one hand, we outline challenges regarding how to conduct related studies and on the other hand what to research so as to improve the validity and reliability of conceptual model quality from the review.

Next, section 2 presents the classification framework for conceptual model quality based on the analysis of its definition. Section 3 summarizes and discusses the current practice in measuring the quality of conceptual models. Section 4 discusses the challenges identified and gives some suggestions on how to better measure conceptual model quality.

2 Classification framework for conceptual model quality

2.1 Quality in conceptual modeling

Definition of conceptual model quality is the first issue to be solved in the quality measurement. However, there is no definition of conceptual model quality accepted universally at present. According to ISO 9000, quality is depicted as the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs [9]. Therefore, Moody defined quality in conceptual modeling as the totality of features and characteristics of a conceptual model bear on its ability to satisfy stated or implied needs [8]. Referred to the function of conceptual model in the system development, then quality in conceptual modeling can be defined as the totality of features and characteristics of a conceptual model that bear on its ability to define requirement in different levels.

Based on the fundamental notion, variant definition of conceptual modeling quality can be bred from different perspectives. For instance, Sun defined quality in use of a conceptual model as the extent to which the conceptual model can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use [10].

Hierarchical structure is widely used in most approaches to quality evaluation. In these structures, quality is decomposed into a set of lower level quality characteristics which are recognizable properties of a product or service [11]. Take software quality for example: the concept of software quality is decomposed into six quality characteristics, which are further divided into 24 quality sub-characteristics, which are measured by 113 quality metrics in ISO/IEC 9126 [12]. The hierarchy structure of software quality is shown in Figure 1. The strict hierarchy of quality concepts is easy to use for quality evaluation because it transfers the abstract notion into measurable concrete metrics. Many researchers in the field of conceptual model quality have established some frameworks consisting of simple lists of quality criteria, which need to be refined at another level.

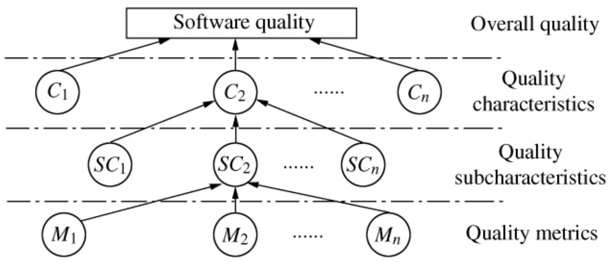

Figure 1 Structure of ISO/IEC 9126 software quality model

2.2 Structure of classification frameworks

Corresponding to the hierarchical structure, especially the level of quality characteristics, many structures of classification framework are established. The original work to articulate a systematic framework consisted of three types of model quality: syntactic, semantic and pragmatic quality [13]. Compared with previous attempts which only resulted in lists of unstructured, vague and often overlapping quality properties [14], the proposal has a both (linguistics and semiotics theory) basis and has been empirically validated [15,16]. Based on Lindland et al.'s framework, extended proposals have been developed (e.g. Kesh [17], Schütte and Rotthowe [18], Moody and Shanks [14]). The main elements of the framework are shown in Figure 2.

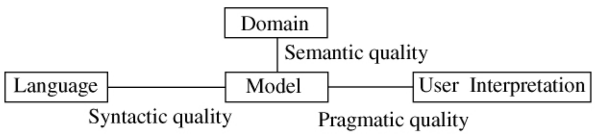

Figure 2 Lindland et al.'s framework for quality of conceptual modeling scripts

According to the framework, quality of a conceptual model is classified into three types. Syntactic quality describes how well the model parallels with the rules of the modeling language. Semantic quality describes how well the model captures the domain of interest within the context of the user. Pragmatic quality captures how well a conceptual model is understood by its audience. Two main quality concepts are involved in these types: completeness and validity. A model is complete if it contains all of the elements of the domain. It is validity if it does not contain any elements that are not in the domain [19].

Based on the identified deficiencies of the Lindland et al.'s framework, Krogstie and Sølvberg proposed an extended quality framework [20] shown in Figure 3.

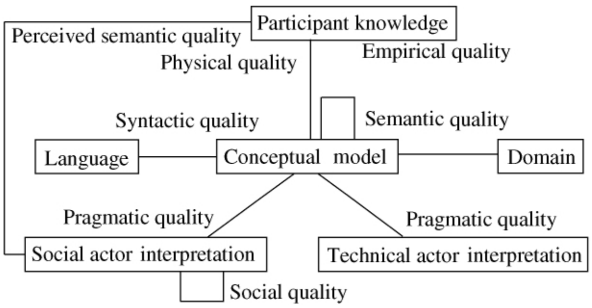

Figure 3 Extended quality framework proposed by Krogstie and Sølvberg

Besides the three types of quality (semantic quality, syntactic quality, and pragmatic quality), the framework incorporated four other types of qualities. The perceived semantic quality is the comparison of participant knowledge and social audience interpretation, partially reflecting the level of true semantic quality. Physical quality involves two aspects of quality means: on one hand, externalization refers to the level of externalization of the knowledge of some social actors in the forms of conceptual models, on the other hand, internalization refers to the level of other social actors' knowledge obtained by making sense of the externalized model. Social quality refers to the level of the agreement on participants' interpretation. Empirical quality is related to error frequencies when the model is used. Adopting the framework, Keng Siau & Xin Tan used cognitive mapping techniques to a popular system development methodology-Soft Systems Methodology to improve the quality of conceptual modeling [21].

Another useful classification dimension is the objects of the study. Geert Poels et al.'s proposed that quality research should pay attention to any (or all) three modeling objects: conceptual model itself, modeling process and modeling facility [19]. Conceptual model itself refers to the product of the modeling activity. Modeling process includes different stages in creating the model. If the modeling process is of high quality, the model that is the result of the process should also be of high quality. The modeling facility includes all of the tools, techniques and controls used in the modeling process.

User conceptual modeling quality dimensions are also induced in the field. Ann Maes & Geert Poels pointed out that there are clear parallels between the perceptual and satisfaction constructs of the Seddon's re-specified D&M IS success model [22] and perceptual conceptual modeling script quality and satisfaction constructs [23]. Then, the overall quality of a conceptual model can be classified as perceived semantic quality as information quality, perceived ease of understanding as system quality, and perceived usefulness and user satisfaction.

The final conceptual model quality research classification dimension is the research goal. Research goals can be classified as understanding, measuring, evaluating, assuring and improving a conceptual model [19]. Research related with understanding quality develops the scales that can be used to determine quality. Measuring quality examines how to apply those dimensions against conceptual models. Evaluating quality explores the correlation between the quality measurements and the real-world experiences with the model. Quality assurance research examines how to ensure that the modeling process actually produces a quality model. The research on improving quality examines how to make conceptual model quality better.

Overall, these structures of classification framework for conceptual modeling quality are summarized in Table 1.

Table 1 Research dimensions of conceptual modeling quality

Types of quality	Object of study	Users´ perspective	Research goal
Syntactic quality	Product	Perceived semantic quality	Understanding quality
Semantic quality	Modeling process	Perceived ease of understanding	Measuring quality
Pragmatic quality	Modeling facility	Perceived usefulness	Evaluating quality
Perceived semantic quality		User satisfaction	Assuring quality
Physical quality			Improving quality
Social quality			
Empirical quality			

3 Current practice in measuring the quality of conceptual models

To review measure practices in the field, Lindland et al.´s framework, which includes syntactic, semantic and pragmatic quality, is adopted in the present study. The purpose of this section is to put forward data on measures used in the study and to give some immediate comments.

3.1 Measure of syntactic quality

Syntactic quality, that seems to be well controlled and can be objectively measured, has the goal of syntactic correctness, that is, all statements in the model are according to the syntax and vocabulary of the modeling language [24~26]. And syntactic correctness is defined in terms of the modeling language, usually. Therefore, syntactic quality is determined by comparing the representation to the language while the meaning of the elements should be preserved [27].

To achieve syntactic quality, having formal syntax in a language is the first and key step [28]. The level of quality would be achieved through errors and deviations checking. Fewer errors and deviations from the rules indicate better syntactic quality.

3.2 Measure of semantic quality

Semantic quality captures the quality of a model in terms of what the model lacks that is present in the domain, as well as what the model includes that is not present in the domain [29]. This category can be described in terms of validity and completeness. However, this quality is hard to evaluate directly because it is difficult to know reality, externalize this knowledge and agree upon it. So when evaluating semantic quality, the only way for users is to refer to their perception of reality reached through observation and internalization. But these perceptions most depend on many uncontrollable factors such as previously acquired knowledge, perceptual psychology effects, cognitive abilities, and ontological and epistemological standpoints that are taken. The evaluation results will be questioned.

Perceived semantic quality, defined as the correspondence between the information that users think the model contains (user interpretation) and the information that users think the model should contain, based upon their knowledge of the problem domain (domain knowledge) [30], should be easier to measure because it serves as an operational surrogate of semantic quality and it does not require verifying the correspondence between model and domain. Nevertheless, this type of quality has rarely been used. The only study was done by Dunn and Grabski to compare the perceived semantic quality of different models [31,32].

The other studies related with semantic quality have chosen other substitutes rather than domain knowledge. Examples include studies employing meta-model analysis [33] and ontological analysis [34]. In particular, the Bunge-Wand-Weber (BWW) ontology [35,36] has often been used as a 'reference theory' for the real-world. Using an ontologically clear and complete grammar does not guarantee the quality of the generated models, but they do make it easier to create good models.

3.3 Measure of pragmatic quality

The pragmatic criterion is concerned with the compliance of the model to aim and purposes for which model was created. And it captures the extent to which model has been selected "from among the many ways to express a single meaning" and essentially deals with making the model easy to understand. Therefore, pragmatic quality addresses the comprehension aspect of the model from the stakeholders´ perspective. It is foremost the question of modeling pragmatics that is of pertinence when trying to ascertain the quality of a model. Jan Mendling & Jan Recker applied the formalism provided by Kühne to clarify the influence of pragmatic concerns on modeling as a mapping activity with choices [37,38].

Note that just as mentioned in Lindland et al.´s work [13], the pragmatic dimension is not only concerned with whether different stakeholders sufficiently understand the model but also assessing the value of the model in helping its interpretants to better make use of it for fulfilling their need. Jan Mending investigated understandability as a proxy for quality of models and its relations with model characteristics, especially pragmatic dimension through empirical approaches [39]. In the most recent SEQUAL version of Krogstie et al.´s framework, the pragmatic quality of a conceptual modeling script has been redefined as the model´s ability to facilitate learning and action [24].

There are several measures and instruments have been developed for evaluating pragmatic quality of conceptual models. Models have been often compared by respects of how well they are understood by users when alternative conceptual models are evaluated. In empirical studies, comprehension task performance usually is used as an indicator of pragmatic quality which should only test whether users comprehend the explicit semantics expressed in a conceptual model [40]. Task accuracy, completion time, and normalized accuracy (i. e. accuracy divided by completion time) are involved as measures used for comprehension task performance [41~43]. In these studies, a conceptual model is considered as a tool to learn about a domain. Under the condition that prior domain knowledge of the model user is low, then the performance on a problem solving task is a measure of how well the conceptual model has helped the user to understand that domain.

Apart from task performance, users´ perception of how easy it was to understand a model is also used as a measure of pragmatic quality in other studies. Such measures involve perceived value [42], perceived ease of use [31,42,44], and user satisfaction [31,44] measures. Especially the perceived ease of understanding measure [45~47] already proposed can be considered as an indirect evaluation of pragmatic quality.

4 Challenges in measuring the quality of conceptual models

In the previous section we reviewed the current practice of measuring conceptual model quality and described some limitations of the measures employed. The aim of this section is to discuss challenges for how to conduct related studies and research into how to measure conceptual model quality.

4.1 Subjective and objective measurement of conceptual model quality

In the reviewed studies two types of measurement of conceptual model quality are involved: subjective measure and objective measure. Subjective measurement mainly focus on stakeholders´ perception or attitudes towards the conceptual model. However, objective measurement concerns aspects of the conceptual model quality not dependent on stakeholders´ perception and these measurement can be obtained, validated in ways not possible for subjective measurement. The distinction between these two measurements is hard to define precisely and has been argued to simplify the nature of measurement in science [48,49]. In the study, we do not attempt to make a substantial epistemological distinction. Rather, we suggest using the distinction to reason about how to choose different measurement and find more complete ways of assessing conceptual model quality.

There are two crucial reasons why we need study both subjective and objective measurement of conceptual model quality. One reason is that they may result in different conclusions regarding the quality of a conceptual model. Even if the same conceptual model were evaluated, different users would achieve varying levels of perceived ease of use or user satisfaction which is an aspect of quality just as mentioned above. Therefore, using both subjective and objective measurement may give a more complete picture of conceptual model quality. Another reason for pursuing the subjective/objective distinction is that for some aspects of conceptual model quality we are interested not only in improving objective performance, but also in enhancing stakeholders' perceptions (perception of ease of use, perception of engagement, and so on). Depending on the specified context, a balanced concern on subjective and objective measurement may help to improve both the user experience and objective performance.

In summary, the first challenge to research is to develop subjective measurement for aspects of measuring conceptual model quality that are currently measured by objective measurement mainly, and vice versa. Then their relation should be evaluated to support related practice.

4.2 Measurement conceptual model quality over time

The majority of the studies reviewed above focus on static (data or information) models, which may reflect the higher level of maturity and standardization of notations in this area. And the conceptual model quality over time (i. e. quality of dynamic models) has so far received very little attention, even though functionality that is reflected by dynamic models is considered to be the most influential determinant of the quality of the final system [12].

In line with ISO/IEC 9126, conceptual model quality over time needs more attention on process quality. Process quality refers to defect prevention rather than detection, and aims to reduce reliance on mass inspections as a way of achieving quality [50]. The objective is to build quality into the production process rather than trying to add it in at the end [8]. According to the quality management literature, improving the process by which products are produced is the most effective way [51]. The challenge appears to establish the research framework for conceptual model quality over time, especially for process quality. In summary, we need a more full understanding of how a conceptual model with high-quality can be achieved over time. Are stakeholders able, over time, to compensate for most quality problems that lead to initial dissatisfaction?

4.3 Studies of correlations between measurement

Lack of understanding of the relation between measurement of measuring conceptual model quality would give rise to many issues in related practice (e. g., confusion with which quality measurement should be employed given concrete context). Studies of correlation between measurement may improve this understanding by informing us whether our measurement contribute something new and what their relation are among other aspects of conceptual model quality.

Empirical testing, that is ignored in previously related studies, is one of the cornerstones of the scientific methods [52] and should be emphasized in future research on correlations between measures of measuring conceptual model quality. In fact, adoption of empirical test in the field not only provides evidences of measurement correlation, but also validates the theoretical basis about what conceptual model quality is and how it can be evaluated.

5 Conclusions

We have reviewed classification framework of conceptual model quality, summarized the current practice of measuring conceptual model quality as well as reviend that practice. According to different criteria, conceptual model quality includes variant research dimensions. Based on linguistics and semiotics theory, conceptual model quality can be classified into syntactic, semantic and pragmatic quality, which is adopted in our study. Notable problems on how conceptual model quality measurying measurement are employed include.

1) measurement of measuring syntactic quality are on the base of formal syntax in a language. However, achievement of this agreement is often hard for different groups, especially for non-native speakers;
2) measurement of measuring semantic quality and related research are lack of "standardized" domain knowledge, namely it is difficult to know reality, externalize this knowledge and agree upon it;
3) measurement of measuring pragmatic quality involves the stakeholders' perception, which is usually obtained depending on stakeholders' characteristics, especially cognitive features.

Based on the review, we proposed several challenges with respect to measuring conceptual model quality. Those challenges include the need to better understand the relation between objective and subjective measurement of conceptual model quality, to extend quality measurement beyond static models, and to study correlation between measurement. Such challenges mentioned above are also the research points we should pay more attention to in future studies.

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