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Measuring Software Product Quality using ISO 9126: A Systematic Review

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ABSTRACT

ISO 9126 software quality model of 2001 is the most comprehensive and widely accepted model. It is a generic quality model that is used in measuring quality of software across computing domains. This study seeks to access the level of application of ISO 9126 model in measuring software quality and its impact on different software domains. We employed a standard methodology for systematic literature review using automated search on four digital libraries for studies published between 2001 and 2016. The results of the systematic review reveal that the model as a whole has played a significant role in measuring software quality across different domains. Out of total 63 primary stud-ies, 30 applied the six characteristics, and 33 papers applied one or more characteristics for measuring software quality. Software component and database are the most evaluated domains, while usability characteristics are the most measured quality. This is the result of the fact that software vendors are moving towards quality user-centred design instead of technology driven designs. Ambiguity resulting from the lack of clear guideline and operational instrument for evaluation is the major shortcoming of this quality model, but were favored by many due to its flexibility to suit the growing software domains.

Key words: ISO 9126, software quality, software domain, quality model, systematic review.

1. INTRODUCTION

Software quality is considered to be essential for the software product success [1]. Quality attainment of software has therefore, become critical for the software designers and developers to ensure the success of their product. A number of definitions of quality have been proposed. The international standards organization (ISO/IEC 9126) defines quality as: “a set of features and characteristics of a product or service that bear on its ability to satisfy specified or implied needs” [2]. While IEEE defines quality as “the degree to which a system, component, or process meets specified requirements and customer or user needs or expectations” [3]. The two definitions aimed at satisfying the user (customer’s need for the software product).

Therefore, it is not enough to deliver products having technical excellence only, but also to have quality of ease of use and fit to user work practices [4]. Correspondingly, the proliferation of wide variety of application areas and their criticality for safety and correctness for business success [5] alerted software system designers on quality [6]. In an attempt to broaden the perception of quality, standard organisations such as ISO 9126 has developed a quality model.

The ISO 9126 model is a quality that is part of the ISO 9000 standards, which is the most important standard for quality assurance [7] and constitutes the most extensive software quality model developed to date [8]. The model represents the entire software product quality attributes in a hierarchical tree structure with characteristics and sub-characteristics. The approach of its quality model was initially published in 1991 and refined over the next ten years by ISO’s group of software engineering experts, to provide a framework for evaluating software quality [8]. This international standard model describes a two-part model for software quality: a) internal and external quality and b) quality in use. The internal and external software quality is the main focus of this review. It divides software quality into six general categories of characteristics: Functionality, Reliability, Usability, Efficiency, Maintainability and Portability.

ISO 9126 is an important software quality model. The definition of software quality characteristics of this quality model provides a useful frame of reference and terminology standardization which facilitates communication concerning software quality [9]. However, ISO 9126 has been superseded by ISO/IEC 25030 SQuaRE (Software Quality Requirements and Evaluation) [10][11][12]. In spite of this fact, we have chosen the ISO 9126 for the review because of it comprehensiveness and contribution in providing guidance towards the measuring and evaluating software quality. In addition, the ISO 25030 standard is based on the ISO 9126 model [13]. Therefore, our work tends to review the impact of ISO 9126 in measuring software quality, such that our future work will evaluate the extent to which ISO 25030 addresses the shortcomings of ISO 9126.

2. REVIEW METHODOLOGY

To effectively undertake a systematic literature review, the guideline provided by Kitchenham [14] was considered. Therefore, the following subsections describe its stages: definition of research questions, search strategy, inclusion and exclusion criteria, quality assessment, data collection and data analysis [14][15].

2.1 Research Questions

The goal of this study is to investigate into research issues concerning ISO 9126 quality model. More specifically, the following research questions were addressed.
RQ1. How much research study using ISO 9126 is conducted since 2001?
RQ2. Which software domains are evaluated with this model?
RQ3. Which characteristics are often evaluated in the model?
RQ4. What are the limitations of this model?

RQ1 defines the search scope period. The current structure of ISO 9126 model was proposed in 2001 [2]. Prior to that there were other quality models promoted by different researchers. In their separate work [7][16] reported such models with comparative analysis. Yet, this is considered to be the most comprehensive and most widely used. Therefore, studies were selected from journal and conference papers to address RQ1.

With respect to RQ2, we considered the software domains that ISO 9126 quality model has used to evaluate within the scope of the study period. While, with regards to RQ3 and RQ4, we have examined the frequently measured characteristics in this model and the limitations as outlined by our primary studies respectively. Whereas, the output of RQ4 will be compared with studies such as Al-Kilidar et. al. [1] and Al-Qutaish [17], which highlighted some of the weaknesses of the model.

2.2 Search Process

In the systematic review, the search process must be transparent and adequately documented [14]. Therefore, in this study, the search process was automated for conference and journal papers published between 2001 and 2016 in four online databases that are Science Direct, IEEE Xplore, Springer Link and ACM digital library. The procedure is mainly to identify candidates for primary studies. The search carried out using search parameters to include keywords on the title and full text article. The search was executed using the inclusive and exclusive criteria and all the authors participate in the review of papers that duel on measuring software quality using ISO 9126 model. Section 2.3 describes the details of inclusion and exclusion criteria.

In order to obtain the desired result and facilitate the search process, a set of search terms/key words were used. This terms were used interchangeably, they are:- “Software quality”, or, “Software quality model”, or, “Software product quality”, or, “Measuring software quality”, or, “ISO 9126”, or, “ISO 9126 model”, or, “Software quality standards”, or, “Quality model”.

2.3 Inclusion and Exclusion Criteria

The main criterion for inclusion as primary study is a conference and journal article that discusses about the measuring of software quality using the ISO 9126 model between 2001 and 2016. More specifically, studies with the presentation of empirical data and results showing discussion on applying ISO 9126 quality model on software and thereby answering the research questions defined in the previous section were considered.

To determine the suitability of a study into the primary study and in accordance with Brereton et. al. [18], the title and abstract were examined by the first author whereas the full papers which were not rejected were examined by all the authors. Meanwhile, papers that have no clear cut on answers relating to the research questions define previously were rejected. Papers such as those that discussed impact of ISO 9126 model, and conceptual reviews. Even though our study comprises 2016, no paper was included for obvious reason that most 2016 papers only mention ISO 9126 as a software quality model or reference a definition, or saying that it has been supersided by ISO 2500 series. Although it was acknowledged that ISO 9126 is the most widely used software quality model. Therefore, the review covers papers from 2001 to 2016.

2.4 Quality Assessment

In the review procedure, quality assessment is aimed at validating the primary studies to determine the strength of their methodology and results. The quality assessment performed by the authors with main objective of ensuring (at least to some extent) our results would be based on good quality empirical studies. To ensure the empirical quality of the primary study, a three-point likert scale questionnaire adopted from Fernandez et. al. [19] was designed with the following questions used in the assessment. Does the study reported empirical research or whether it was merely a ‘‘lessons learned” report based on expert opinion? Is the aim and objectives clearly reported? Is there an adequate description of the context in which the research was carried out? Is there adequate description of measuring software quality using ISO 9126? The first three questions were extracted from Dybå and Dingsøyr [20] as a criterion for screening the quality of a primary study that is based on principles of good practice for conducting empirical research in Software Engineering. Upon completion of the quality assessment, a total of 63 studies were selected to be included in the review as primary studies.

Table 1: Extracted Data from Papers Analysed.

Author	**Date**	**Citation type**	**Domain**	**Characteristics**	**Publisher**	**Method**	**Limitation**
Ahn et al. [35]	2013	Journal	Detailed Clinical models	All	Elsevier		Ambiguity
Alrawashdeh et al. [36]	2014	Conference	Business	All	IEEE	Experiment	Not adequate
Alvaro et al. [37]	2006	Conference	Software component	All	IEEE	Case study	General
Alves et al. [38]	2010	Conference	Database	All	IEEE	Experiment	Not easy to understand
Andreou and Tziakouris [39]	2007	Journal	Software component	All except portability	Elsevier	Case study	General
Asadi et al. [40]	2015	Journal	Visualization/GUI	Maintainability & Usability	Springer	Experiment	
Athanasiou et al. [41]	2014	Journal	Test code	Maintainability	IEEE	Experiment	
Aversano and Tortorella [23]	2013	Journal	Open source	All	Elsevier	Experiment	
Baklizi and Aighyaline [42]	2011	Conference	e-learning	All	IEEE	Case study	
Bakota et al. [43]	2011	Conference	Source code	Maintainability	IEEE	Experiment	Ambiguity
Behkamal et al. [32]	2009	Journal	e-commerce	All[1]	Elsevier	Case study	Too general
Bertini et al. [44]	2013	Journal	Database/IR	Usability	Springer	Experiment	
Bertoa et al. [34]	2006	Journal	Software component	Usability	Elsevier	Experiment	Lack of standard in usability
Biscoglio & Marchetti [45]	2014	Conference	Digital media	All	IEEE	Experiment	Not adequate
Chua and Dyson [31]	2004	Conference	e-learning	Functionality, Reliability, Usability and Efficiency	ACM	Case study	Usability will require additional sub-characteristics
Corral [46]	2012	Conference	Mobile	All	ACM	Experiment	
Correia et al. [47]	2009	Conference	System properties	Maintainability	IEEE	Experiment	
Crespo [48]	2013	Conference	GUI	Usability	IEEE	Experiment	
Cunha et al. [29]	2012	Conference	Spread sheet	All	IEEE	Experiment	General
Davuluru et al. [49]	2014	Conference		All	IEEE	Survey	No guideline, no emphasis on users view
Djouab et al. [50]	2014	Journal	Embedded system	All	Springer	Survey	
Farago et al. [51]	2014	Conference	Source code	Maintainability	Springer	Case study	
Fitrisia & Hendradjaya [52]	2014	Conference	Information System	Functionality, Reliability, Maintainability & Portability	IEEE	Case study	
Güleşir et al. [53]	2013	Journal	Visual Language	Usability	Elsevier	Experiment	
Hegedűs [54]	2013	Conference	Code	Maintainability	IEEE	Case study	Ambiguity
Heitlager et al. [9]	2007	Conference	System properties	Maintainability	IEEE	Experiment	Ambiguity
Hendradjaya [55]	2014	Conference	Learning system	Functionality, Reliability, Usability & Efficiency	IEEE	Case study	Some characteristics require expertise
Hindle et al. [56]	2013	Journal	Database	All	Springer	Experiment	
Idri et al. [25]	2013	Conference	Mobile	All	IEEE	Experiment	General
Jung [57]	2007	Journal	Database	All except Reliability	Elsevier	Experiment	Ambiguity
Jung et al. [58]	2004	Journal	Database	All except Reliability	IEEE	Survey	Ambiguity
Kanellopolus and Heitlager [59]	2008	Conference	Source code cluster	Maintainability	IEEE	Experiment	Ambiguity

Kannangara and Wijayanayake [60]	2013	Conference	Code	Maintainability	IEEE	Experiment	
Khan et al. [61]	2013	Journal	Collaborative learning	Usability, Functionality	Elsevier	Survey	
Kim and Lee [27]	2009	Conference	Consumer electronic	Reliability, Maintainability and Portability	IEEE	Experiment	General
Kolahdouz-Rahimi et al. [62]	2014	Journal	Refactoring	All	Elsevier	Case study	
Kuo [63]	2013	Journal	Software component	All	Springer	Experiment	
Kurtel [24]	2013	Conference	Code	Maintainability	IEEE	Experiment	General
Lee K. and Lee [64]	2005	Conference	Software component	All	IEEE	Experiment	Lack practical guideline
Lin et al. [65]	2013	Journal	Web services	All	Elsevier	Experiment	
Liu et al. [66]	2014	Conference		Functionality	IEEE	Experiment	
Losavio et al. [33]	2004	Journal	Architectural designs software	All	Elsevier	Case study	General
Malak et al. [67]	2010	Journal	Web application	All	ACM	Experiment	
Mantoro [68]	2009	Conference	Pervasive computing	All	ACM	Experiment	
Medina-Flores & Morales-Gamboa [69]	2015	Journal	Learning system	Usability	IEEE	Case study	
Moumane & Idri [70]	2015	Conference	Mobile	All	IEEE	Analysis	Not adequate
Nabil et al. [71]	2011	Journal	Web application	Functionality, Usability, Maintainability & Portability	Elsevier	Survey	Ambiguity
Neukirchen et al. [30]	2008	Journal	Test specification	All	Springer	Experiment	Too general
Orehovački et al. [21]	2013	Journal	Web applications	All except Maintainability	Elsevier	Experiment	
Park and Jeong [72]	2013	Journal	Cloud computing	All except portability	Springer	Experiment	General
Revuelta-Martínez et al. [22]	2013	Journal	Database/IR	Usability	Elsevier	Experiment	
Scholtz et al. [73]	2013	Journal	Business	Usability	ACM	Experiment	Not adequate
Seffah et al. [74]	2006	Journal	GUI applications	Usability	Springer	Survey	Static
Simon & Rösch [75]	2015	Conference	Embedded system	Usability	IEEE	Case study	
Stefani and Xenos [21]	2008	Journal	e-commerce	Functionality, Usability, Efficiency and Reliability	Springer	Survey	General
Stefani and Xenos [76]	2011	Journal	e-commerce	Functionality, Usability, Efficiency & Reliability	Elsevier	Survey	General
Svensson et al. [13]	2013	Journal	Mobile	All	Elsevier	Experiment	No standard interpretation
Tchoffa et al. [77]	2014	Conference	Information system	All	IEEE	Case study	
Tiwari & Chakraborty [78]	2015	Conference	Software component	All	IEEE	Analysis	Too general
Washizaki et al. [79]	2006	Conference	Embedded system	All	ACM	Experiment	
Yuen and Lau [80]	2011	Journal	Mobile	All	Elsevier	Case study	Ambiguity
Yuen [81]	2012	Conference	Software component	All	IEEE	Experiment	
Yuhana et al. [82]	2014	Conference	Information system	All	IEEE	Experiment	

2.5. Data Collection

Completion of inclusion or exclusion procedure and quality assessment phases allow for the extraction of data from the primary studies. The data extracted from each of the selected study were; the source and full reference, publication type, year of publication, publisher, software domain evaluated, characteristics applied or measure, method of application and limtation(s) mentioned. In accordance with Kitchenham et. al. [15], one researcher extracted the data from the primary studies and another checked the extraction. During the checking of the extracted data, all disagreement arising from the activity were discussed and resolved.

2.5.1 Data Analysis

The data extracted in section 2.5 was presented in Table 1 and statistically analysed.

3. RESULT AND DISCUSSION

In this section, we discuss the findings of the review by providing answers to our research questions defined in section 2.1.

3.1. How Much Study Using ISO 9126 Has Been There Since 2001?

In general, a total of 63 relevant studies are identified in the sources that we searched as shown in Table 1. These studies directly applied ISO 9126 quality model to measure software product quality. On the other hand, Table 2 reveals that IEEE has been in the front runner in publication related to ISO 9126 quality model. Out of the whole publications, 32 are conference papers while, 31 are journal publications. However, a number of publication were made on ISO 9126 model that are not included because of the fact that they do not address the research issues outlined in this paper.

Table 2: Number of publication per publisher

Publisher name	Publication
IEEE	30
Elsevier	17
ACM	6
Springer	10

There is significant increase in the publication on studies related to measuring software quality with ISO 9126 model over the last years. The early years of the model record no publication on its application to evaluate software quality. Conversely, the subsequent years has recorded a reasonable number of publications, with 2013 having the highest number of publications. Some of the later publications [21][22][23][24][25][26] acknowledge the fact that the ISO 9126 model has been replaced with ISO 25000 series, yet they choose to use it. As a result, the following reasons where mentioned to that effect: (1) the model is widely accepted (2) that the ISO 25030 is based on ISO 9126 (3) ISO 9126 was more widespread in industry.

3.2. What Software Domains are Being Evaluated with this Model?

ISO 9126 quality model has been used to evaluate a wide range of software application domains. Furthermore, our review reveals that software component, database, source code and mobile are the most often evaluated domains. More specifically, 7 studies related to software component and database which made up 11.5% of the primary studies, source code and mobile made 9.8% each, e-commerce and e-learning systems accounts for 8.2% each. Consumer electronics, web applications and GUI designs has 6.6% each. Test specification and information systems account for 3.3% and 4.9% respectively.

Others are, spread sheet, architectural design software, open source applications, clinical models, and cloud computing amount to 1.6% each. Component technology is of great concern to software factories due to its reusability capabilities [27]. It is important to note that in these domains, ISO 9126 model was used in some cases to propose a number of models to evaluate these distinct software domains [28][29][30][31].

3.3. What Characteristic is Often Evaluated in the Model?

This question aims to identify the often evaluated or measured characteristics in the model. The results begins by taking into account the model as a whole, which we found that 30 out of the 63 studies apply all the characteristics in measuring quality of a given software product, thereby representing 47.6% of the studies.

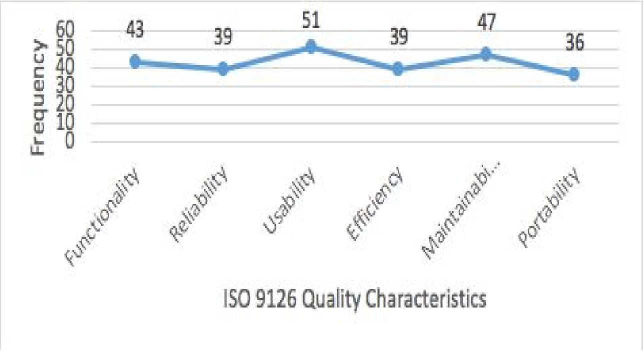

Figure 1: Frequency of evaluated quality characteristics

While, 33 articles representing 52.4% uses the model in part, taking into account one or more quality characteristics. More analytically, the results in Figure 1 suggests that usability is the most often evaluated characteristic. From the results of the review usability represents 20% of studies related to measuring software quality with ISO 9126 model against 18.4% of maintainability, 16.9% of functionality, 15.3% each goes for reliability and efficiency and 14.1% for portability.

On the applicability of these characteristics within the stated period of study some of the studies not only apply the model but also went further to call for additional attributes as in the case of usability [32]. Furthermore, most of the characteristics were measured using experimental method.

3.4. What are the Limitations of this Model?

With respect to answering this question, a number of limitations associated with ISO 9126 quality model were identified. Prominent among the limitations identified from our primary studies is that the model is ambiguous in defining its characteristics and sub-characteristics. From our findings, 14.5% of our primary study reveals that ambiguity is a limitation to this model which could give room to for different perception of some of the model's matrices.

On the other hand, 19.4% states that the model is too general and therefore, will always require customization to allow for use in specific domains [31][33][34]. Some studies (6.5%) pointed out that the model is not adequate, hence may require additional characteristics and sub-characteristics.

Other weaknesses outlined are static, and those that relates to studies on usability characteristics, which either says there is lack of standard [35] or call for additional sub-characteristics for usability [32]. All these made up 12.9% of the studies. Finally, 29 (46.8%) of the total primary studies reported no limitation with respect to ISO 9126 quality model. Interestingly, this limitations agrees with most of those reported by Al-Qutaish [17] on the investigation of the weaknesses of ISO 9126 international standard.

4. LIMITATIONS OF THE STUDY

This section of the paper discusses the limitation of the systematic review and implication on future work. The limitations are related to preference of publication and selection. Publications from journal and conferences were only taken into consideration. However, workshops and symposium publication were apparently ignored. This could threaten the validity of this study. Selection preference was reduced (at least to some extent) by defining our inclusion and exclusion criteria in order to get the most relevant studies. In the first stage of inclusion and exclusion which involves checking of the title and abstract was done by the first author only. Hence, it Is an additional limitation to this study. In an effort to increase accuracy in data collection, the stages were conducted by all the authors and all inconsistencIes were resolved by consensus.

5. CONCLUSION

This paper has presented a systematic review to analyse the application of ISO 9126 in measuring software quality. A total of 63 studies were reviewed out of which 30 studies used the quality model as whole while, others uses one or more characteristics to evaluate quality of a software product. In addition, the model or its part has been employed to evaluate a number of software domains which includes prominently software component and database.

Usability is considered as the most important aspect of software quality, hence, been the most often measured characteristics in the model. This is as the result of the fact that software vendors are moving towards user-centred design instead of technology driven designs. Ambiguity has been the most reported limitation in our primary studies.

Another limitation according to the review is that the model is too general and therefore require customization to effectively apply it to ever growing software domains. This limitation, nonetheless, is also seen as the strength of model, due to its flexibility to do just that.

With respect to future work, further work is intended to extend the systematic review with more primary studies and also take specific characteristics within the model. Also in our future study, we intend to look in details the specific limitations of ISO 9126 and examine the extent to which Software product Quality Requirements and Evaluation (SQuaRE) in ISO/IEC 25030 has addressed these specific deficiencies and subsequently, its implication for developing an improved software quality to meet the challenges of ever growing computing domains.

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