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A REVIEW ON REQUIREMENTS VALIDATION FOR SOFTWARE DEVELOPMENT

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ABSTRACT

Requirement validation is an important phase in software development project in order to certify that the captured requirements are the exact representations of the users' needs and expectations. This phase helps to identify and avoid requirements errors from propagating to the later stage. In this paper, we performed a literature review that investigated the trend in software requirements validation approach studied in a decade from the year of 2007 until 2016. Here, we investigated the types of contributions, modes of approaches, requirements types and the techniques that were commonly used and proposed for requirements validation. In this study, we found that many studies contributed new methodology/approach for validating the functional requirements using semi-formalise method. The Unified Modelling Language (UML) models were the most favourite models for this purpose. Furthermore, we found that requirements prototyping was the most used technique for requirements validation. This study also reported the most important requirements quality criteria that need to be validated and fulfil in order to develop high quality software. From the results we found that quality of consistency, correctness and completeness were most frequently validated in requirements validation.

Keywords: *Software Engineering, Requirements Engineering, Requirements Validation, Quality of Requirements*

1. INTRODUCTION

Requirements errors such as inconsistency, incompleteness, and incorrectness can lead to extensive rework and unrecoverable failures [1]. In addition, fixing those errors at the later stage is more difficult, time consuming and costly to a software development project [2]–[5]. Fortunately, such unnecessary errors can be avoided with a proper requirements validation. The main objective of requirements validation is to certify that the elicited requirements are the exact representations of the users' needs and expectations [6]–[15].This key activity can help to identify and prevent requirements defects and errors from disseminating to the later stage [4][16]. It also helps to improve requirements quality, reduce the development time, cost and risks in order to develop high quality software that meets the users' expectations [17][18].

The research in the area of requirements engineering has been recognised since mid-1980s [7]. Since its inception, there have been many literature or systematic mapping studies covering various aspects of requirements engineering such as requirements specification [19][20], requirements prioritisation [21], and agile requirements engineering [22][23]. However, we found out that there are very limited studies in requirements validation; the sub-area of requirements engineering. The same has been mentioned in previous studies where the evidence about requirements validation techniques are still yet to be done [24]. We found a few literature studies on requirements validation [25][26], but they are not comprehensive. Therefore, we conclude that the study in requirements validation area is still immature and inadequate, which needs further investigation.

Here in this study, we conducted a systematic literature review to investigate the pattern in the requirements validation practices proposed by various studies in a decade from the year of 2007 until 2016. We focus on the requirements validation stage in the field of software engineering to investigate the approaches, techniques and tools as

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proposed by previous studies. The literature map in Figure 1 show the scope of our study. We would also like to discover the most important requirements quality factors/criteria that were commonly validated by previous studies. Following this section we discuss our research method followed by the results and discussion and finally we conclude our work.

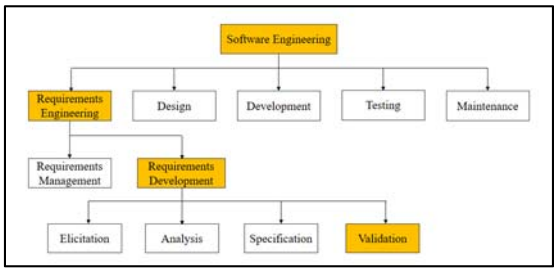

Figure 1: Literature map of our study.

2. RELATED WORKS

This paper is not the first one exploring the subject of requirements validation in software engineering. Our study complement the result presented by [14]. Previously, M. Kamalrudin and S. Sidek [14] have presented the various gaps existing within the process of validating requirements especially for consistency management. In this new study, we investigate the trend of requirements validation for checking the quality of requirements. We found an empirical study presented by U. Raja [25] highlighting the pros and cons of the general requirements validation techniques. Similarly, a survey have been conducted by [26] highlighting the issues of traditional requirements validation techniques in Global Software Development (GSD) environment. These two studies discussed on the general/traditional techniques in requirements validation, which is contrast to our study. We focus to seek the pattern and trend of requirements validation to present the approaches, techniques and tool proposed by various studies in a decade.

3. RESEARCH METHOD

The primary focus of our study was to identify the current trend in software requirements validation practice and the important qualities criteria of requirements that were validated in the selected studies. Next section discusses our research questions for this study.

2.1 The Research Questions

We have formulated the following research questions for this systematic analysis of software requirements validation.

RQ1: *What was the current trend in the requirements validation approach/technique/tool that was applied or proposed in the studies?*
This research question aimed to understand and identify the trend in requirements validation practice. Here we identified their contributions in this area, the types of requirements they validated (functional, non-functional or both), the methods/techniques used or proposed, the modes of the approaches and the domain application of the studies.
RQ2: *What were the quality criteria of requirements that were validated by the studies?*
The objective of this research question was to identify the types of qualities criteria for requirements that were validated in the studies.

2.2 The Search Process

The primary search process in our study involved the use of standard online database such as Scopus, ACM Digital Library, IEEE Xplore, Science Direct and Springer Link. We searched all the relevant papers published between 1st January 2007 and 31st December 2016 from these online databases. We have developed the search phrases in order to find the answers to our research questions, which are as follow:
("requirements" OR "specification") AND ("validation" OR "validate" OR "validity") AND ("methodology" OR "technique" OR "method" OR "tool") AND ("quality" OR "quality criteria" OR "quality factor")
Our initial search using the above search phrase returned 146,327 papers. For example, the Science Direct database initially returned 139,777 papers, which included the publications in the areas such as social science, healthcare, pharmaceutical and applied energy. Therefore, we set some inclusion and exclusion criteria to gather relevant publications. We described our study selection in the following section.

2.3 The Study Selection

We set some inclusion and exclusion criteria for our study selection to include as many relevant publications as possible. The inclusion criteria were:
(a) The paper must be directly related to early requirement validation topic in the area of requirements engineering and software engineering.
(b) The studies must be published between 2007 and 2016.

The main exclusion criterion was that the requirements validation papers are not targeted at Software Engineering or Requirements Engineering

area. Furthermore, the following exclusion criteria were also applied to:

(a) The papers that are not related to early requirements validation in requirements engineering phase. We excluded the papers that discuss on the validation of requirements at the testing phase, which is validating the developed software system or implementation-under-test (IUT) against the requirements.
(b) Review papers that use the terms such as "systematic literature review", "literature review", "literature survey", "systematic analysis" or "meta-analysis". We only included the papers that propose a new methodology, technique and tool for requirements validation.
(c) Papers that are not written in English.

Figure 2 describes the paper selection process. A total of 146,327 papers were found in our primary search in the specified databases. After removing duplicates and applying the inclusion and exclusion criteria only 4122 papers were selected. 399 relevant papers were selected after reading the titles, abstracts and conclusions. Finally, only 30 papers were selected after applying the quality assessment.

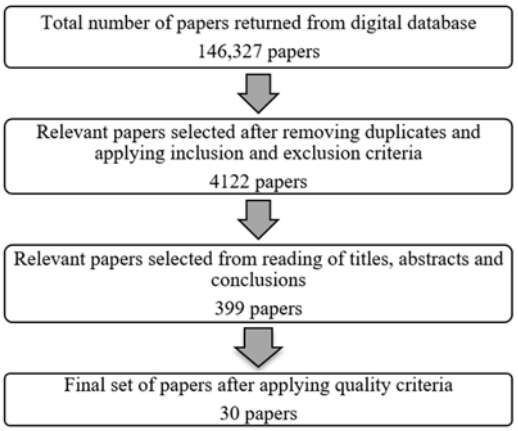

Figure 2: Flow of the paper selection process

2.4 Quality Assessment

We applied the quality criteria to assess the quality of the selected papers. We evaluated each paper using the quality assessment criteria listed in Table 1. The list of criteria was adapted from [23][27].We calculated the quality score of each selected paper based on the six criteria as listed. The quality scores of the result of the selected study are shown in Figure 3.

Table 1: Quality Assessment Criteria

Sections	Criteria	Response grading
Introduction	1. Does the introduction provide an overview of requirements validation? Is the context of the research well addressed?	Yes = 1 point, Partially = 0.5 point, No = 0 point
	2. Is the research aim/objective clearly defined?	Yes = 1 point, Partially = 0.5 point, No = 0 point
Method	3. Is the research methodology clearly defined?	Yes = 1 point, Partially = 0.5 point, No = 0 point
Results	4. Are the findings clearly stated? Do the results help to solve the requirements validation problems?	Yes = 1 point, Partially = 0.5 point, No = 0 point
	5. Based on the finding, how valuable is the research?	>80% = 1 point, <20% = 0 point, in between = 0.5 point
Discussion / Conclusion	6. Are there any limits or restrictions imposed on the conclusion claim?	Yes = 1 point, Partially = 0.5 point, No = 0 point

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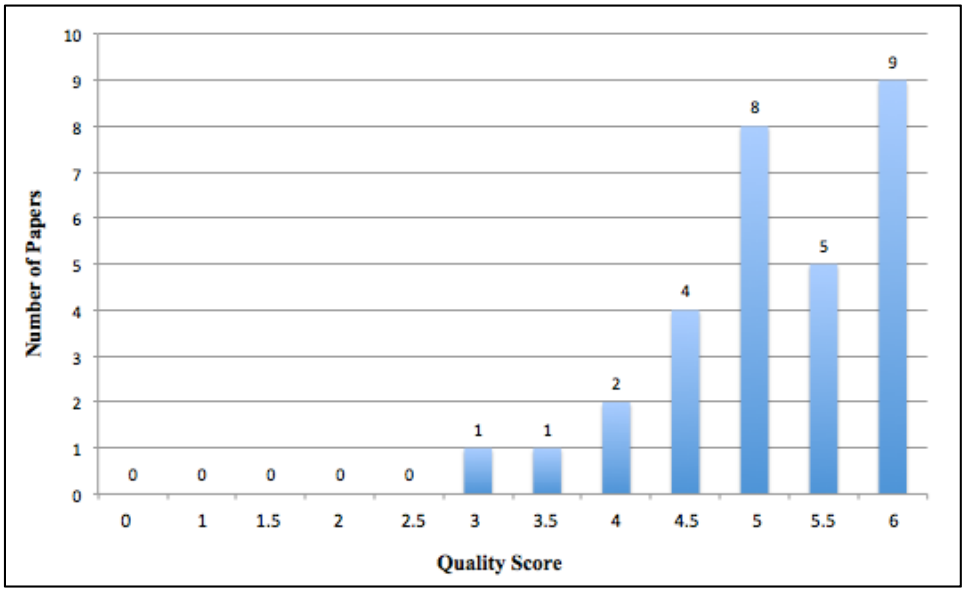

Figure 3: Quality scores of selected papers

4. DATA EXTRACTION RESULTS

We found 30 papers published between 1st January 2007 and 31st December 2016 that discussed on the topic of requirements validation in the early stage of software development. For each of the paper, we identified the year of publication, type of publication, type of contribution, the proposed name of their approach/tool and the domain of application of their approach. The results are presented in Table 2.

3.1 (RQ1): What was the current trend in requirements validation approaches/technique/tool that was applied or proposed in the studies?

To answer this research question, we identified the contributions of the studies in the requirements validation area, the types of requirements they validated (functional, non-functional or both), the approaches, methods/techniques and tools used or proposed, the modes of the approaches and the domain applications of the studies. We represent the results of our analysis in both heat map (Figure 4) and pie charts (Figure 5 and Figure 6). There were four types of contributions on the software requirements validation studies; methodology, technique, framework and tool. From our analysis, methodology was the highest contribution from researchers to perform requirements validation, which was 50% from the relevant studies (See Figure 5). This was followed by the tool, technique and finally framework.

The studies' approaches in software requirements validation were divided into three types of modes; formal, semi-formal and informal. Formal approach has a rigorous, mathematical basis [6]. In contrast with formal approach is informal approach that is more flexible and qualitative in nature such as natural language. In between this approach is semi-formal approach, which involves the usage of models/diagrams such as UML model. From our study, it was found that semi-formal approach was the most preferred approach followed by the formal method. Figure 6 shows the modes of approaches' distribution in more detail. Many studies focused on validating the functional requirements instead of non-functional requirements. However, there were also studies that focused on validating both types of requirements.

In general, the most commonly used techniques in software requirements validation included; prototyping, animation, inspection, reviews, simulation, model-based, scenario-based, testing-based and view-point oriented [13][26][28][29]. These techniques were used in all the three modes of approaches for requirements validation. Studies such as [30][4][31] used a combination of these techniques in their proposed approaches. Prototyping seemed to be the most favourite technique used in the studies, followed by simulation, model-based and testing-based requirements validation. The same result was found by previous study [32] where the prototyping and user-interface mock-up were the most frequently used in requirements verification and validation. Furthermore, many studies have acknowledged that prototyping was an effective way to ensure valid requirements and also helped the requirements

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engineer to understand the requested requirements from client-stakeholders [33][31][34][35]. Figure 4 shows that formal method techniques were applied more by the researchers. From this analysis, it was found that formal reasoning was the most used technique in formal requirements validation method. Theorem proving was the least used in this area of study. Natural language processing (NLP) was the most used technique in informal approach compared to control natural language.

As shown in Figure 6, almost half of the studies (47%) used semi-formal approach for requirements validation, which utilised the use of models/diagram. To further investigate the usage of these models we classified the models using a heat map representation similar to the approach in Figure 4. From our analysis, as shown in Figure 7, UML model was the most used model in the semi-formal approach of requirements validation. From this result, state machine diagram and use case were the most favourite among researchers followed by the sequence, class and state diagram. The other models used for requirements validation were Essential Use Case (EUC) model, domain/conceptual model, business model, conventional use case and message sequence chart. The task model and structured/entity-relationship (ER) diagram were the least used models in requirements validation.

Table 2: Studies published between 1st January 2007 and 31st December 2016

Study Ref.	Year	Paper Type	Contribution				Approach / tool Name	Domain Application
			Methodology / Approach	Method / Technique	Framework	Tool		
[36]	2007	Journal				X	CPN Tool	Healthcare System
[37]	2008	Conference	X				NRVA	Web-based system
[33]	2008	Journal				X	AutoPA3.0	Library system
[38]	2009	Conference				X	EuRailCheck	Transportation (train)
[39]	2009	Conference			X		ACE Framework	Online discussion / forum
[3]	2009	Conference				X	Executable OCL Checker (EOC)	Business
[40]	2009	Conference	X				-	Elevator system Transportation
[41]	2009	Conference				X	WTM Simulator	Invoice Management System
[4]	2010	Conference		X			SQ^2E	Production line
[5]	2010	Conference	X				-	-
[10]	2011	Conference	X				CoReVDO	E-Commerce
[42]	2011	Conference				X	MaramaAI	ATM System
[43]	2011	Conference	X				-	Automotive
[44]	2011	Conference				X	VRP	Embedded software system
[30]	2012	Conference				X	AsmetaRE	ATM System Invoice Order System

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								Gate Control System Elevator System
[45]	2012	Conference	X				-	Library system
[46]	2012	Journal	X				Othello	Transportation
[47]	2013	Conference		X			-	Insurance
[48]	2013	Journal	X				-	Multi-Agent System
[49]	2014	Conference		X			CuRV	Smart Phone
[50]	2014	Conference	X				SpecQua	Healthcare system
[51]	2014	Conference	X				-	Automotive
[52]	2014	Conference	X				-	Library system
[1]	2014	Conference		X			-	Automotive
[31]	2015	Journal	X				ReVAMP	Business
[53]	2015	Journal		X			-	Business (online shopping)
[54]	2015	Journal		X			SimTree	Healthcare Device
[55]	2016	Conference	X				-	Transportation (train)
[56]	2016	Conference	X				MobiMEReq	Mobile apps
[57]	2016	Journal	X				Automated Secure Acceptance Testing Framework (ASATF)	Faculty Search Committee System

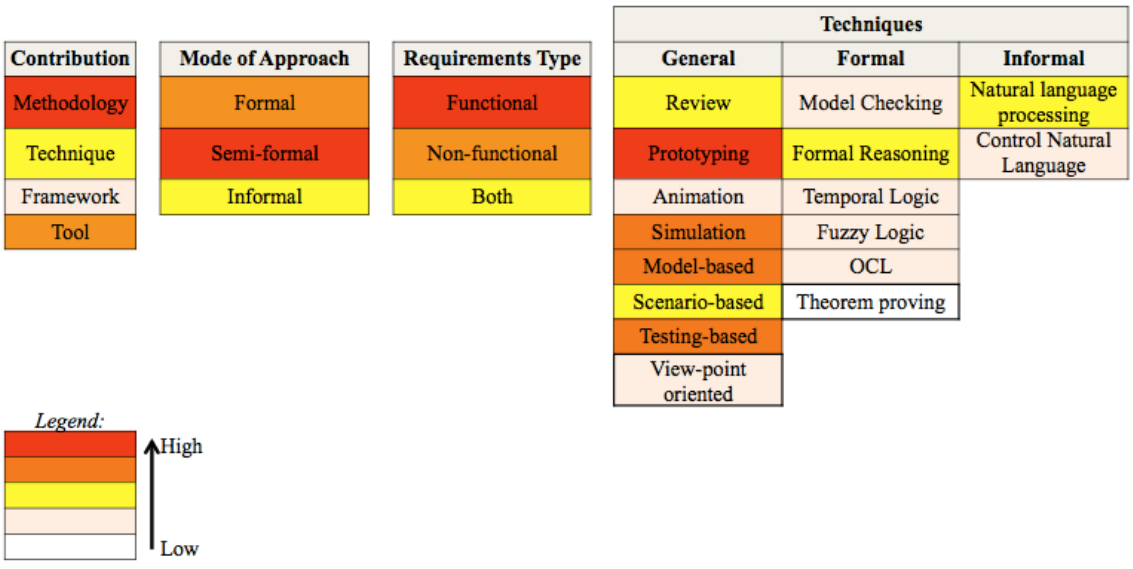

Figure 4: Heat map representation: Categorisation of type of contribution, mode of approach, requirements type and requirements validation techniques.

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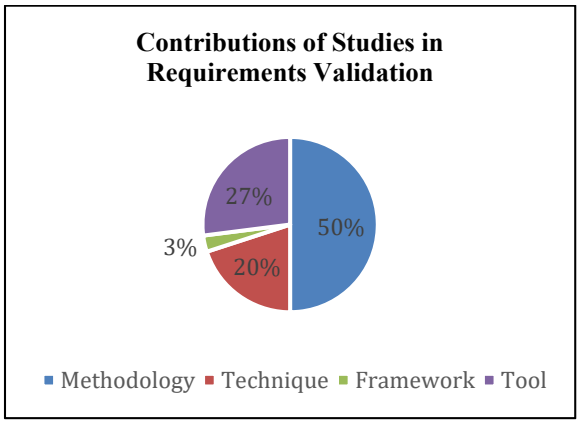

Figure 5: The contributions of studies in requirements validation

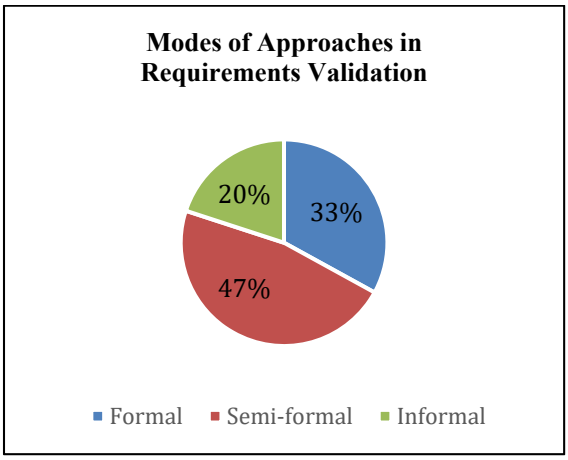

Figure 6: Modes of approaches in requirements validation

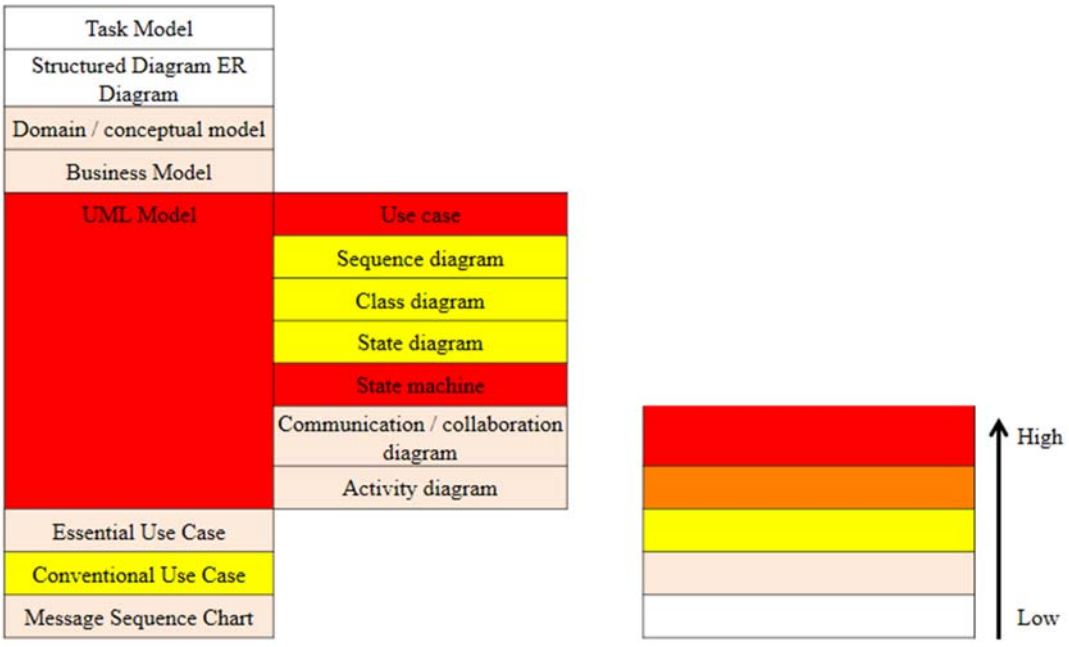

Figure 7: Heat map representation: classification of the model used as a semi-formal requirements validation approach

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3.2 (RQ2): What are the quality criteria of requirements that were validated in the studies?

Next, we investigated the types of qualities criteria for requirements validated by the studies. There were multiple and diverse quality criteria in order to achieve good requirements document. Here we listed the common quality criteria as described in [7][58][12], which included correctness, completeness, consistency, unambiguity, verifiability, traceability, comprehensibility, readability, priority (ranked), validity and modifiability. Table 4 and Figure 8 show the common qualities criteria of requirements that were considered in related studies. Table 4 shows that most of the studies had multiple quality criteria validated in their studies. The quality criteria with the highest frequencies were *consistency* followed by the *correctness* and *completeness*. Then, *traceability*, *unambiguity* and *verifiability* resulted with the same frequencies, followed by *comprehensibility*, *validity*, *readability*, and *priority (ranked)*. From our analysis, none of the studies were discussing about *modifiability*. This analysis also showed that the most important quality factors for requirements were consistency, correctness and completeness. This important causal relationship is supported by various studies [59][60][61][62].

Table 3. The matrix of requirements qualities criteria validated by the studies.

Study Ref.	Correctness	Completeness	Consistency	Unambiguity	Verifiability	Traceability	Ranked/ Priority	Modifiability	Comprehensibility	Readability	Validity
[36]	X										
[37]	X										
[33]	X										
[38]			X								
[39]	X		X								
[3]			X								
[40]			X								
[41]											X
[4]	X										
[5]			X								
[10]		X	X	X	X	X			X		
[42]			X								
[43]			X							X	
[44]	X	X	X			X					
[30]	X										
[45]		X	X	X							
[46]			X								
[47]		X			X	X	X		X		
[48]	X	X	X								
[49]			X								
[50]			X								
[51]			X								
[52]	X	X									
[1]	X										
[31]	X	X									
[53]		X		X	X						
[54]	X	X									
[55]	X	X									
[56]	X	X	X			X					
[57]	X	X	X	X	X						
Total	**15**	**12**	**17**	**4**	**4**	**4**	**1**	**0**	**2**	**1**	**1**

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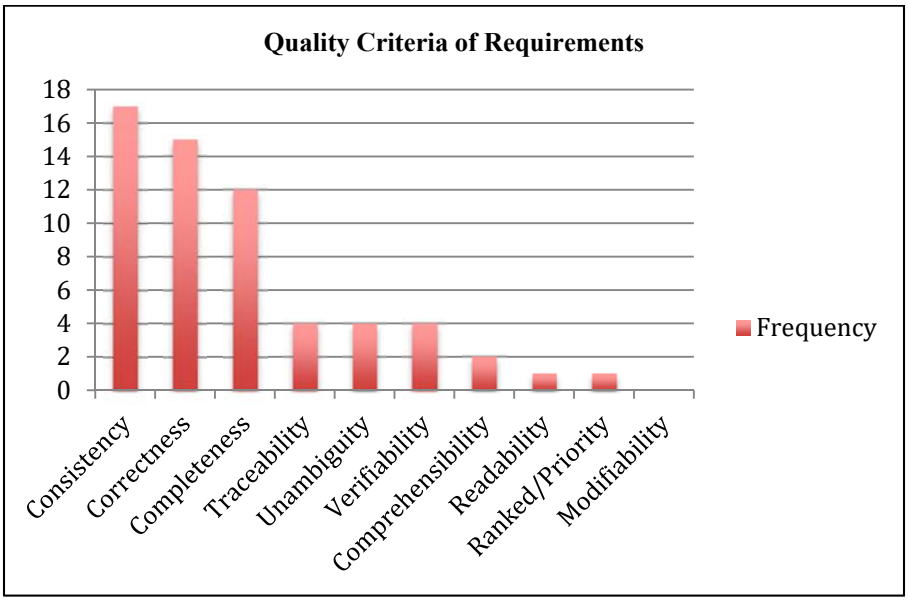

Figure 8. The validated quality criteria of requirements

5. LIMITATION OF STUDY AND FUTURE WORKS

Our study has some limitation but they can be ameliorated in future work. Firstly, the results of our review only include the studies found from the year of 2007 until 2016. Any relevant studies published outside the time-frame was not included. Secondly, this study only provide the classification to show the trend in requirements validation practice. Therefore, in the future, we would like to conduct a comparative analysis of the approaches, techniques and tools for deeper insight in this topic.

6. CONCLUSION

This paper discusses the software requirements validation in the earliest stage of software development. Requirements validation is one of the most important phases in software development project to avoid requirements errors from propagate to the later stage. This phase is also crucial in order to achieve the best quality of requirements that reflects the user's expectation and needs. From our analysis, many studies were validating the functional requirements using the semi-formal approach/method. For this, UML models were the most frequent used for requirements validation. In terms of the techniques, prototyping was the most favourite followed by simulation, model-based and testing-based requirements validation. Our analysis also found that the most important quality criteria of requirements were consistency, correctness and completeness.

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