THE IMPORTANCE OF REQUIREMENT QUALITY CRITERIA

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ABSTRACT

Well-crafted requirement specifications contribute to enabling software develop- ers to implement technical solutions quickly and with high quality. The aim is to contribute to the implementation of good requirements engineering. As the quality of requirements is particularly dependent on compliance with requirement quality criteria, the importance of these criteria is analyzed in relation to predictive success. The most important quality crite- ria identified were correctness, unambiguity, completeness, and comprehensibility. Moreover, it is possible to improve the quality of requirement specifications in specific quality dimen- sions through targeted revision. In the course of the RCP/AE experiment, a significant im- provement was observed in consistency, correctness, and completeness. Ambiguity was also significantly reduced. Only the improvement in testability was not statistically significant.

KEYWORDS

Requirements Engineering, Requirement Quality Criteria

1. INTRODUCTION

The quality of requirements specifications plays a crucial role in preparing software development. Contradictory, ambiguous, or incorrect requirements specifications can lead to additional effort and financial losses. During the requirements analysis, the Business Analyst must describe the functional requirements with an appropriate level of quality. These quality standards have been specified by IEEE Std. 830-1993 [IEE93] and ISO/IEC/IEEE Std. 29148:2011(E) [ISO11].

This study aims to answer the following research questions:

- **RQ1:** How should the quality criteria for requirement descriptions be prioritized?
- **RQ2:** Does the revision of requirement specifications successfully improve their quality?

Section 2 provides an overview of selected related work. This is followed by an analysis in Section 3, which serves to prepare the answering of the aforementioned research questions. Section 4 presents the methodology through which the results described in 5 were obtained. Section 6 outlines the validity scope of the results. The discussion concludes with a summary and an outlook.

2. RELATED WORK

To ensure that the effects of a change request are identified and considered, Williams and Carver propose a model for the systematic analysis of requirements [WC]. This model

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categorizes changes using a decision tree framework: (1) the motivation is identified, (2) the change is categorized, (3) the effect is classified, (4) relevant attributes are determined, and (5) both functional and non-functional aspects, along with logic and runtime behavior, are documented [WC]. After this general analysis, a more specialized evaluation of the impact on specific subsets of system elements and their behavior is recommended [WC]. The systematic collection of detailed change information can improve the quality of impact analysis. The technical report [WC] focuses on presenting this model, which functions as a reference framework and merits further testing.

Pasham discusses the challenges arising from requirement volatility due to weak specifi- cations [Pas24]. Such specifications often fail to meet IEEE standards, leading to missed quality, time, and cost targets [Pas24]. As a solution, Pasham recommends greater atten- tion to requirements engineering and strict adherence to quality standards [Pas24]. Given that requirement changes are inevitable, developing high-quality specifications helps man- age volatility. Pasham recommends that specifications (1) define the software's goal, (2) describe the system context, and (3) include both functional and (4) non-functional require- ments [Pas24]. Requirements documents should (I) meet IEEE standards, (II) be designed as living documents, (III) be quality assured, (IV) contain concise and clear definitions, (V) avoid redundancy, and (VI) be described as formally as possible [Pas24]. Considering the developer's perspective when writing requirements can help assess their implementability [Pas24].

Prasetya et al. conduct a literature review of factors influencing *Software Change Requests (SCR)* and approaches to managing them [PPP24]. Their goal is to help software vendors achieve business objectives through better management of SCRs [PPP24]. Reviewing 18 studies, they identify project size, complexity, stakeholder involvement, and the quality of requirements documentation as key influencing factors [PPP24]. They emphasize the importance of a well-structured change management process, especially through the use of change impact analysis to assess the effects of change requests on software components [PPP24, p. 2213].

Prasetya et al. also highlight the challenge of prioritizing change requests [PPP24, p. 2204]. A machine learning-based approach for prioritization is presented by dos Santos et al. [dSdSLP24]. They trained a machine learning model on historical data from 1,441 prioritized change requests [dSdSLP24]. To process the textual data, they standardized capitalization, removed articles and pronouns, and applied regression analysis to identify high-weight keywords for critical requirements [dSdSLP24].

3. ANALYSIS

SRS shoud be...	IEEE Std. 830-1993	ISO/IEC/IEEE 29148:2011(E)
...correct	✓	(✓) (see p. 29)
...unambiguous	✓	✓
...complete	✓	✓
...consistent	✓	✓
...ranked for importance [...]	✓	(✓) (see p. 11)
...verifiable	✓	✓
...modifiable	✓	(✓) (see p. 37 ff.)
...traceable	✓	✓
...comprehensible	(✓) (see p. 10 - 14)	(✓) (see p. 8, 25)
...necessary		✓
...implementation free	(✓) (see p. 5)	✓
...singular		✓
...feasible/affordable		✓
...bounded		✓
...validate	(✓) (see p. 7)	(✓) (see p. 8, 29)

Fig. 1. Overview of quality criteria as requirements for specification documents, differentiated according to the standards IEEE Std. 830-1993 and ISO/IEC/IEEE 29148:2011(E). Content-related requirements are shown in blue, while those serving requirements management are shown in light gray. Own illustration, created with [Cor19b]

The standards IEEE Std. 830-1993 [IEE93] and ISO/IEC/IEEE Std. 29148:2011(E) [ISO11] define quality criteria that requirement specifications should meet. Figure 1 summarizes and compares the quality demands of these standards. Hruschka limits his analysis to the ten IEEE criteria, which state that requirements should be understandable, complete, agreed upon, correct, testable, prioritized, traceable, and modifiable [Hru14, p. 123–125]. Accordingly, the scope is limited to the quality criteria of IEEE Std. 830-1993. In Figure 1, the quality criteria are categorized based on whether they represent domain-specific requirements (blue text) or requirements for the management of requirements (light gray text). The focus is further restricted to those quality criteria that define domain-specific requirements.

4. METHOD

In the present study, the methods RCP/GP and RCP/AE were applied. These are described in detail below. RCP/GP refers to a survey, while RCP/AE represents an experiment.

a. RCP/GP: Evaluation of Requirement Quality Criteria

To address RQ1, the RCP/GP method is applied. Dual bachelor students in computer science and business informatics are asked to prioritize the IEEE quality criteria unambiguity, consistency, understandability, completeness, agreement, correctness, testability, prioritization, traceability, and modifiability, as limited in Section 3. Each participant assigns a unique numerical value from 1 to 10 to each criterion, where a lower number indicates a higher priority. The Ranking function from [Men] is used for this purpose. The resulting priority is treated as an ordinally scaled variable.

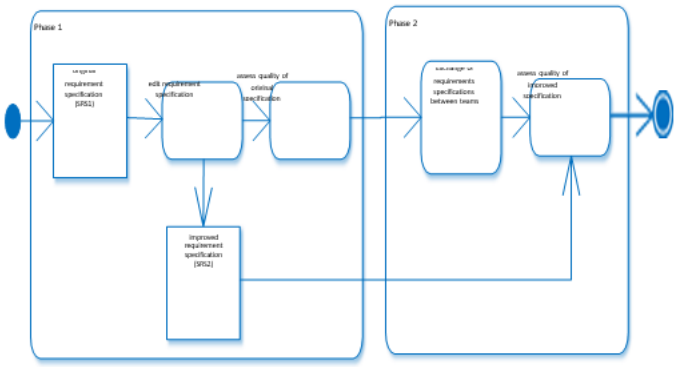

Fig. 2. Overview of the procedure of the RCP/AE experiment. Own illustration, created with Microsoft© Visio© 2021 [Cor21]

For the evaluation of RCP/GP, the following method is applied:

- **RCP/GP/M1**: Comparison of the priorities of the quality criteria

A total of 34 individuals participated in the RCP/GP survey. Participants could skip quality criteria, which led to some criteria being evaluated by fewer individuals. Seven of the ten criteria were rated by 33 participants, while the remaining three were rated by 34. In method RCP/GP/M1, the location measures (minimum, 0.25-quantile ($q_{0.25}$), median, 0.75-quantile ($q_{0.75}$), and upper bound of normal values) are calculated for each criterion and displayed in a box plot. The upper bound of normal values is calculated as $q0.75 + \frac{3}{2}(q0.75 - q0.25)$.

b. RCP/AE: Experiment On Requirements Quality Improvement

The research methodology RCP/AE was previously described in [Kuh26]. It is the same experiment referred to as RCP/AE in the aforementioned paper. In the context of this research, specific alternative aspects are examined within the experiment. The following description has therefore been adapted accordingly. Indeed, as described in [Kuh26], the experiment was conducted in three phases. However, since only two phases are relevant in the context of this research, only these will be described below.

In Phase 1, teams are formed, and each is given a basic requirement, referred to as a requirements specification requirement (see Figure 5). These specifications lack detail and contain quality deficiencies. Participants revise the specifications into improved technical specifications. At the end of Phase 1, participants evaluate the quality of the original specifications. In Phase 2, groups exchange their technical specifications. Based on the initial requirements, Groups I and IV, and Groups II and III exchange their specifications. Each group evaluate the received technical specifications using the quality criteria, see Figure 1.

A total of 30 individuals participated in the RCP/AE experiment. As in RCP/GP, participants could skip individual questions, so response counts vary by phase and question. Table 1 summarizes the questions and number of responses.

Table 1. Participant Information of the Requirements Experiment

Phase	Assessment	n
Phase 1	unambiguous	28
	consistent	26
	correct	28
	verifiable	28
	complete	28
Phase 2	unambiguous	26
	consistent	26
	correct	26
	verifiable	26
	complete	26

To address the research questions, data from RCP/AE is analyzed using the following methods:

- **RCP/AE/M1**: Analysis of the quality of the requirements shown in Figure 5 and how it develops from Phase 1 to Phase 2
- **RCP/AE/M2**: Analysis of the effectiveness of the requirement revisions
- **RCP/AE/M3**: Analysis of the impact of initial requirement quality on the resulting technical specification
- **RCP/AE/M4**: Analysis of how the manifestation of requirement quality criteria affects prediction success

As part of the RCP/AE/M1 investigation, the arithmetic means of the evaluated quality criteria for the requirements in the requirements and functional specifications are calcu- lated and compared. The effectiveness of the requirement revisions is examined using the RCP/AE/M2 methodology after the data has been prepared. In the data preparation phase for RCP/AE/M2, the ratings of participants who did not assess all quality criteria are ex- cluded. Consequently, RCP/AE/M2 is based on n=26 data sets. The effectiveness of the requirement revisions is then evaluated independently of individual requirements by com- paring the mean values and standard deviations for each quality criterion between Phase 1 and Phase 2. As a result, RCP/AE/M2 considers the overall outcome across all require- ments. For each quality criterion, average ratings are calculated across all requirements for each phase. In addition, standard deviations for each criterion and phase are computed.

Based on a two-tailed hypothesis test, the significance of the changes in quality criteria from Phase 1 to Phase 2 in the overall result is assessed. The evaluation is performed using a significance level of 5%. The RCP/AE/M3 investigation examines whether the quality of a requirement in the requirements specification influences the quality of the corresponding requirement in the functional specification. To investigate this potential contribution of the initial quality of a requirement to the achievement of result quality, a regression analysis is conducted within RCP/AE/M3. This is based on a comparison of the average evaluations of the quality criteria between the requirements and functional specifications. It should be noted that the quality criteria for the requirements specifications are not assessed by the same participants who evaluate the corresponding functional specifications. Therefore, a direct comparison based on participant-level data is not possible. The aggregation of data based on the average ratings per quality criterion and phase was performed via a database query. Only those data sets with available ratings were automatically included in the calculation of average values per quality criterion and phase. To examine the in- fluence of requirement quality on forecasting success, a regression analysis is conducted in RCP/AE/M4. The requirement ratings at the end of Phase 2 are compared with the forecasting success of the participants' own team. The requirement ratings in the respec- tive quality criteria are treated as independent variables to explain the development of forecasting success in RCP/AE/P3/2. To analyze the relationship between requirement quality and

forecasting success, an ANOVA analysis is conducted using [Cor19a].

5. RESULTS

a. Analysis of RCP/GP: Priority of Quality Criteria

As outlined in Section 4.1, the analysis of the priorities assigned to the quality criteria of requirements is carried out in RCP/GP/M1 through a comparison of priorities. The depiction in Figure 3 illustrates the location and dispersion measures of the prioritized quality criteria of requirements in the form of a boxplot diagram. With a median of 3, Correctness and with a median of 3.5, Clarity are prioritized most highly. The median priority for the criteria Completeness and Comprehensibility is 4. The criteria Consistency and Modifiability have a median of 5. Testability is prioritized with a median of 6. The criteria Alignment and Traceability have a median of 7. The importance of the criterion Prioritization is rated the lowest, with a median of 8.

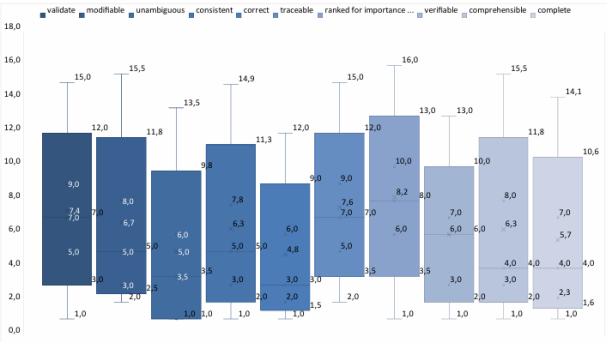

Fig. 3 Measures of dispersion and central tendency of the prioritizations of requirement quality criteria. Own illustration, created with [Cor19a] and [Cor19b]

b. Analysis of RCP/AE: Insights From The Experiment On Requirements Quality

The procedure of the RCP/AE requirements experiment and the methods applied for investigation are described in Section 4.2. In RCP/AE/M1, the development of the quality of the requirement specifications is examined. Figure 4 illustrates the different evaluations of the specification requirement (P1) compared to the functional specification requirement (P2), differentiated by quality criteria and by requirement, as defined in Table 5. The 3D diagram clearly shows that, overall (rows labeled with total), the quality of the functional specification (P2) was rated higher than the requirement specification (P1). However, when examining individual requirements, it becomes evident that the quality of the functional specification requirement is not always rated higher. For example, the completeness or clarity of functional specification requirements in the domain Sales Planning were rated lower than their corresponding requirement specification. Within the scope of RCP/AE/M2, a further investigation of the effectiveness of the requirement revisions is necessary.

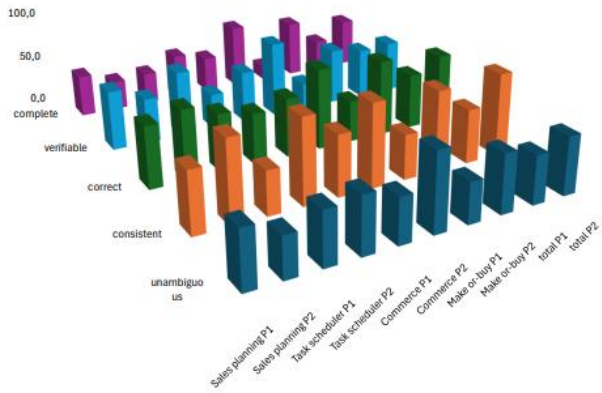

Fig. 4. Comparison of the requirement quality between specifications and functional requirements, differentiated by criteria and individual requirements. Own illustration, created with [Cor19a] and [Cor19b]

Figure 6 presents, across all requirements, the overall results of revising the requirement specifications to create functional specifications. The before revision data reflect average quality assessments of the requirement specification, while the After revision data represent the average assessments of the functional specification. It is evident that the functional specification is consistently rated as higher in quality. The greatest improvements were found in the criteria Consistency (+29.4%), Completeness (+17.3%), and Correctness (+14.7%). The smallest improvement was observed in Testability (+3.7%).

Domain	Requirement
I) Commerce	Development of a price calculator (gross price based on the net purchase price, value-added tax rate, and a desired profit margin).
II) Task scheduler	Development of a program that enables scheduling for a task list under sequential processing.
III) Sales planning	Development of a program that calculates the break-even quantity based on variable unit costs and total fixed costs, indicating the sales volume at which production becomes cost-effective.
IV) Make-or-buy	Development of a program that supports make-or-buy decisions.

Fig. 5. Overview of the initial requirement specifi- cations, serving as the starting point of the exper- iment. Already published in [Kuh26]. Own illustra- tion, created with [Cor19b]

In line with Section 4.2 regarding RCP/AE/M2, a significance analysis was conducted to evaluate the effectiveness of requirement revisions. Figure 7 presents the results of this analysis, as well as the location and dispersion measures per quality criterion and phase. As anticipated from Figure 6, a statistically significant improvement in the quality of the functional specification over the requirement specification was found for nearly all criteria (α = 5%). Only the improvement in Testability was not statistically significant. In RCP/AE/M3, the influence of the initial quality of requirements on the result of a revision was examined. Separate regression analyses were performed to assess whether the initial quality scores for each criterion in the requirement specification could explain the corresponding quality in the functional specification. The results, summarized in Table 2, indicate that no statistically significant correlations were identified at a 5% significance level.

An additional regression analysis was conducted in RCP/AE/M4 to determine whether quality

characteristics such as Clarity, Consistency, Correctness, Testability, and Complete ness influence the accuracy of change requirement predictions. As described in Section 4.2, a 5% significance level was applied. The analysis found no statistically significant influence of any individual quality criterion on prediction success. The resulting t-statistics for the multivariate regression were:-0.96 for Clarity,-0.14 for Consistency,-1.12 for Correctness,-0.23 for Testability, and 0.51 for Completeness.

6. THREATS TO VALIDITY

The findings presented here are limited in their significance due to the small number of participants. The number of individuals who took part in the experiment or survey does not allow for conclusions that can be regarded as universally valid. Consequently, these findings

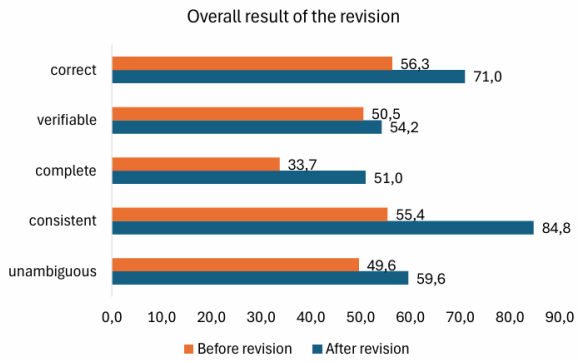

Fig.6.Overallresultofthesuccessoftherequirementsrevision.Ownillustration,createdwithMicrosoft© Excel©[Cor19a]andMicrosoft©PowerPoint©[Cor19b]

Criterion	Phase 1	Phase 2	Assessment
unambiguous	$\bar{x}$ =49,62; s = 19,51	$\bar{x}$ = 59,58; s = 30,14	significant improvement
consistent	$\bar{x}$ = 55,42 ; s = 28,35	$\bar{x}$ = 84,77; s = 20,10	significant improvement
complete	$\bar{x}$ = 33,73; s = 24,95	$\bar{x}$ = 51,00; s = 32,68	significant improvement
verifiable	$\bar{x}$ = 50,54; s = 29,27	$\bar{x}$ = 54,19; s = 35,06	no significant improvement
correct	$\bar{x}$ = 56,35; s = 25,18	$\bar{x}$ = 70,96; s = 29,41	significant improvement

Fig.7.Significanceanalysisofthechangesinrequirementqualitycriteriafromthespecificationdocument comparedtothefunctionalspecification.Ownillustration,createdwithMicrosoft©Excel©[Cor19a]and Microsoft©PowerPoint©[Cor19b

Table2.InvestigationoftheContributionofInitialRequirementQualitytotheAchievementofOutcome Quality.CalculatedwithMicrosoft©Excel©[Cor19a]

Criterion	t-Statistik	adj. R^2
unambiguous	-0.87058	-0.70658
consistent	-0.05646	-1.99047
complete	-0.57978	-1.24527
verifiable	-0.47377	-1.45006
correct	-0.28605	-1.77309

Should be considered only as initial indications. It should also be noted that, in any case, the

results must be verified before practical application. For example, it is necessary to determine whether there are specific circumstances in the respective area of consideration (such as within a particular company or domain) that need to be taken into account. The evaluation of the IEEE quality criteria conducted as part of RCP/GP (cf. [IEE93] [ISO11] & [Hru14, p. 123–125]) was carried out in general terms in the present work. In this regard, it should be noted that an assessment of the same quality criteria, as undertaken during RCP/AE, is normally conducted in the context of a functional requirement. The evaluation of quality criteria independent of requirements is possible; however, a general statement may need to be revalidated when applied to specific matters in the context of the respective requirement. For instance, it can generally be assumed that the assessment derived from RCP/GP, according to which the Correctness of requirement specifications holds the highest priority, must be accurate. However, the assessment of the importance that requirement specifications must be modifiable may be prioritized differently depending on the context. It can be assumed, for example, that the necessity to modify requirement specifications is not equally weighted in all projects, which also affects the priority of this quality criterion.

7. CONCLUSION

This study has examined the importance of quality criteria that must be fulfilled by requirements specifications (RQ1).

Regarding RQ1, the priorities of quality criteria for requirements specifications were identified in a survey conducted as part of RCP/GP. The assessments were provided by dual study bachelor students with programming experience. The criteria identified as most important for requirements specifications were correctness, unambiguity, completeness, and comprehensibility.

Within the framework of the RCP/AE experiment, relationships concerning the quality of requirements specifications were also examined. The application of RCP/AE/M2 demon strated that the targeted revision of a requirement can improve the quality of its specification in terms of unambiguity, consistency, completeness, and correctness. In the course of the regression analysis RCP/AE/M3, it was investigated whether the quality of the initial requirements (requirements specification) influences the quality of the derived requirements (functional specification). The results showed no evidence that the initial quality has a significant impact on the quality of the revised requirement specification. Consequently, even poor requirements specifications can be improved.

Using the RCP/AE study data (following RQ1), it was evaluated whether the quality of a requirements specification influences the success of predicting change requests. Although the regression analysis RCP/AE/M4 could not demonstrate that the quality of a requirements specification has a significant influence on the success of predicting potential change requests, this does not mean that the typical positive effects of high-quality specifications do not occur.

The insights gained from this study cannot be considered universally valid due to the small scope of the investigation. For subsequent research building on this work, it would be advisable to expand the survey and experiment to include more participants. By repeating the methodologies with a larger number of participants, it could be determined whether the findings presented here are generally applicable. Furthermore, it would be beneficial to ex amine the contribution of specific requirements engineering approaches with regard to their effect on the quality of requirements specifications. For example, the study in [Kuh25b, p. 4964– 4967] showed that goal process analyses are conducted for goal definition. It would be worthwhile to investigate, for instance, whether the quality of requirements specifications is positively influenced by conducting goal process analyses. Furthermore, it should also be examined how the quality

criteria are applied in the context of the documentation of the 3D model [KS23b] as part of the presented reference model. It would also be worth investigating whether the use of platforms that support communication and collaboration in requirements engineering within software engineering [Kuh24] influences the importance of quality criteria. Further insights could be gained by examining the effect of quality attributes as quality-related factors (QRFs) [KS23a] in the context of a simulation.

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