

Managing Quality Requirements Using Activity-Based Quality Models

Stefan Wagner, Florian Deissenboeck, and Sebastian Winter
Institut für Informatik
Technische Universität München
Garching b. München, Germany

ABSTRACT

Managing requirements on quality aspects is an important issue in the development of software systems. Difficulties arise from expressing them appropriately what in turn results from the difficulty of the concept of quality itself. Building and using quality models is an approach to handle the complexity of software quality. A novel kind of quality models uses the activities performed on and with the software as an explicit dimension. These quality models are a well-suited basis for managing quality requirements from elicitation over refinement to assurance. The paper proposes such an approach and shows its applicability in an automotive case study.

Categories and Subject Descriptors

D.2.1 [Software Engineering]: Requirements/Specification;
D.2.9 [Software Engineering]: Management—*software quality assurance (SQA)*

General Terms

Measurement, Documentation, Management

Keywords

Quality requirements, quality models, activities, stakeholders

1. QUALITY REQUIREMENTS

Quality requirements are usually seen as part of the *non-functional* requirements of a system. Those non-functional requirements describe properties of the system that are not its primary functionality. “Think of these properties as the characteristics or qualities that make the product attractive, or usable, or fast, or reliable.” [23] Although this notion of non-functional requirements is sometimes disputed, there always exist requirements that relate to specific qualities of the system [13]. We call those demands *quality requirements*.

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1.1 Problem

Quality requirements are an often neglected issue in the requirements engineering of software systems. A main reason is that those requirements are generally difficult to express in a measurable way what also makes them difficult to analyse [21]. One reason probably lies in the fact that quality itself “[...] is a complex and multifaceted concept.” [12] It is difficult to assess and thereby also the definition of quality requirements is a complex task. Especially incorporating the various aspects of all the stakeholders is often troublesome. Hence, the problem is how to elicit and assess quality requirements in a structured and comprehensive way.

1.2 Contribution

We propose a 5-step approach for managing quality requirements using a two-dimensional quality model [8]. This quality model uses activities as one dimension and describes the influences of system entities (and their attributes) on those activities. These two dimensions can conveniently be used as a structure for quality requirements as well. The stakeholders define the activities they perform on and with the system. They provide the most abstract level for quality requirements. Refinements can be made by analysing which system entities are affected by which activities. Finally, a direct traceability from the quality assurance to the quality requirements is given by the quality model. This is the case because the model can be used as basis for quality assurance techniques such as reviews.

1.3 Outline

We start with describing related work in quality modelling and eliciting and structuring quality requirements in Sec. 2. Sec. 3 introduces activity-based quality models and their advantages over traditional approaches. In Sec. 4, we propose an approach to elicit and refine quality requirements based on such activity-based quality models. The relation to assuring the requirements is described in Sec. 5. Then, in Sec. 6, the approach is validated in a case study. Final conclusions are given in Sec. 7.

2. RELATED WORK

Various approaches for non-functional requirements have been proposed. The standard IEEE Std 830-1998 [15] considers requirements specifications in general. It concentrates strongly on functional issues and quality requirements play only a minor role. Ebert discusses in [11] an approach for managing non-functional requirements. He classifies them in *user-oriented* and *development-oriented* that gives them

a first structure. However, this is still too coarse-grained to be applied fruitfully. Also more general approaches such as [6, 20] do not impose a sufficient structure on the quality requirements that foster elicitation or assurance. More structure is provided by the UMD approach [2]. However, it focuses mainly on *issues* that should be avoided and hence do not provide enough connection to the stakeholders. Finally, Doerr et al. [9] included the use of quality models in their approach to non-functional requirements. However, the used quality models themselves provide no direct connection to the stakeholders.

3. QUALITY MODELLING

To be able to efficiently manage quality requirements one needs a means to express them in a concise and consistent manner. Since the 1970ies a number of *quality models* have been proposed to achieve this [3, 10, 17, 19, 22]. However, as is argued in [8] these approaches have a number of shortcomings. Most importantly, they fail to make explicit the interrelation between system properties and the activities carried out on or with the system by the various stakeholders. We regard the omission of activities as a serious flaw as the activities performed on and with the system largely determine the overall life-cycle cost of a software system. Moreover, the activities provide a natural criterion for the decomposition of the complex concept *quality* that many existing approaches lack.

To address these problems, we propose a consequent separation of activities and system entities. This separation facilitates the identification of sound quality criteria and allows to reason about their interdependencies. To illustrate the activity-based quality model we use the quality attribute *maintainability* that is known to have major influence on the total life-cycle cost of software systems.

The 1st dimension of the quality model consists of the activities carried out on or with the system by the various stakeholders. In the case of maintainability the set of relevant activities depends on the particular development and maintenance process of the organisation that uses the quality model, e.g. the IEEE 1219 standard maintenance process [14]. As activities can be conveniently structured in activities and related sub-activities, the 1st dimension of the model actually forms a tree: the *activities tree*.

The 2nd dimension of the model, the *entities tree* describes a decomposition of the *situation*. We use the term *situation* here to express that this tree is not limited to a description of the software system itself but also describes relevant aspects of the organisation that develops the system. This is necessary as organisational aspects like development processes and the provided infrastructure are known to have a major impact on the expected maintenance effort.

To achieve or measure maintainability in a given project setting we need to establish the interrelation between entities and activities. This relationship is best expressed by a matrix as depicted in the simplified Fig. 1.

As the figure shows, to be able to express these relations, one needs to equip the entities with fundamental *attributes* like *consistency*, *completeness*, *conciseness* or *redundancy*. Now entities and activities can be put into relation by the identification of *impacts*. An impact is defined as a relation between an entity/attribute tuple and an activity where + expresses a positive and - a negative impact.

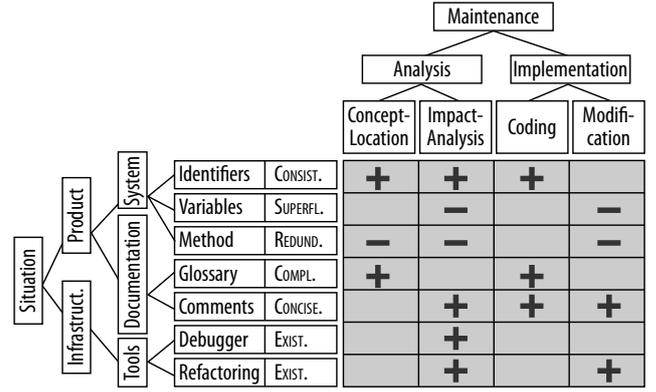


Figure 1: Maintainability model

$$[\text{Entity } e \mid \text{ATTRIBUTE } A] \xrightarrow{+/-} [\text{Activity } a]$$

An example in the figure is [Identifiers | CONCISENESS] $\xrightarrow{+}$ [Concept Location] that expresses that the conciseness of identifier names has a positive influence on the activity *concept location*. The negative impact of superfluous variables on the modification of existing code is expressed as [Variables | SUPERFLUOUSNESS] $\xrightarrow{-}$ [Modification]. The example shows that even the apparently simple attribute EXISTENCE can be very powerful when we want to state that a proper infrastructure, e.g., a debugger has an influence on specific activities.

Such a model is well-suited to classify quality requirements as the activities provide a straight-forward relation between the stakeholders, that ultimately define quality requirements, and the software system. For the example of maintainability, the related stakeholder is the developer. His main activity *maintainance* can be broken down in more tangible subactivities. This subactivities can then be related to situation entities via basic attributes. In [25] it is presented how such a model can be used for the quality attribute *usability*. The central stakeholder is the user and his core activity *usage* can be decomposed in more specific subactivities like *reading*. They can be related to concrete entities like the fonts used in the user interface.

4. ELICITATION AND REFINEMENT

The main approaches to elicit quality requirements are either checking several requirements types and building prototypes [23] or using positive and/or negative scenarios (use cases and misuse cases) [1]. Although we believe that both approaches are valid, important, and best used in combination, the incorporation of the quality model described in Sec. 3 can improve the result by defining more structure.

We use the structure induced by the quality model to elicit and refine the quality requirements. This elicitation and refinement process consists of 5 main steps that should be supported by the established elicitation techniques mentioned above. An overview is shown in Fig. 2. The steps are strongly oriented at using the two trees contained in the quality model and aim at refining the requirements to quantitative values as far as possible. Obviously, the approach is influenced by the availability of a suitable quality model. Ideally, an appropriate quality model exists that shows the needed activities and entities. However, this will



Figure 2: The process steps for quality requirements elicitation and refinement

often not be the case but many activities and the upper levels of the entities tree can usually be reused or found in the literature [8]. Then the quality model should be refined in parallel to the requirements.

4.1 Identifying Relevant Stakeholders

The first step is, similar as in other requirements elicitation approaches, to identify the stakeholders of the software system. For quality requirements, this usually includes users, developers and maintainers, operators, and user trainers. Obviously, other stakeholders can also be relevant for the quality requirements. When the stakeholders have been identified, the quality model can be used to derive the activities they perform on and with the system. For example, the activities for the maintainer include *concept location*, *impact analysis*, *coding*, or *modification* [8]. Especially the activities of the user can be further detailed by developing usage scenarios.

4.2 Ranking Activities

In the next step, we rank the activities of the relevant stakeholders according to their importance. If not all needed activities are defined in the model, it will be extended accordingly. This results in a list of all activities of the relevant stakeholders. On top of this list are the most important activities, the least important at the bottom. Importance hereby means the activities that are expected to be performed most often and which are most elaborate. The justification can be given by expert opinion or experiences from similar projects. This list will be used in the following to focus the definition and refinement of the requirements.

4.3 Defining Requirements Qualitatively

Now, we need to answer the question how well we want the activities to be supported. The answers are in essence qualitative requirements on the software system. For example, if we expect rather complex and difficult concepts in the software because the problem domain already contains many concepts, the activity *concept location* is desired to be *simple*. These qualitative statements are needed for all the activities. Depending on the amount of activities to be considered, the ones at the bottom of the list might be ignored and simply judged with *don't care*.

4.4 Refining Using the Entities Tree

As described in Sec. 3, the entities tree contains the entities of the software and its environment that are in some way relevant for the quality of the system. The entities tree organises them in a well-defined, hierarchical manner that fits perfectly to the task of refining the requirements elicited based on the activities. The quality model itself is a valuable help for this. It actually captures the influences (of properties) of entities on the activities. Hence, we only need to follow the impacts the other way round to find the entities

that have an influence on a specific activity. If these influences are incomplete in the current model, this step can also be used to improve it. This way, consistency with the later quality assurance is significantly easier to achieve. For the definition of the refined quality requirements, the attributes defined for the entities can be used. For example, a detailed requirement might be that each object must have a state accessible from outside because this has a positive effect on the *test* activity. We refine those higher-level requirements in more detail that have been judged to be important in the last steps.

4.5 Quantifying Requirements

Finally, the goal is to have quantitative and hence easily checkable requirements. We can quantify the requirements on the activity-level or on the entity-level. On the activity-level, this would be, for example, that an average *modification* activity should take 4 person-hours to complete. Requirements on the entity-level might be quantitatively assessable (cf. [8]) depending on the attribute concerned. For example, *needless code variables* can be counted and hence an upper limit can be given. We assume that it is theoretically possible for any requirement to define it quantitatively. Yet, it is not always feasible in practice as either there is no known decomposition of the requirement or it is considered too elaborate.

5. ASSURANCE

The model acts as a central knowledge base for the quality-related relationships in the product and process. Therefore, it is also a well-suited basis for assuring that the defined quality requirements have been fulfilled. Fig. 3 shows how the model can be used in several ways for constructive as well as analytical quality assurance (QA).

Constructive QA is supported by the automatic generation of *Quality Guidelines* from the model. These guidelines define what *Developers* should do and what they should not do in order to meet the quality requirements expressed by the model. For analytic QA, the *Quality Engineer*, uses manual *Reviews* as well as the *Quality Reports* generated by *Quality Analysis Tools* to evaluate if quality requirements are satisfied. Like the guidelines, *Checklists* that support the manual reviews are automatically generated from the model. To be used efficiently, review checklists are required to be as short as possible [4]. As we annotate the properties in the model, whether they are automatically, semi-automatically, or only manually assessable, review checklists can be limited to issues that require manual evaluation and thereby be kept as concise as possible. Checklist length can be further limited by selecting only the subset of the quality model that is relevant for the artefact type being reviewed. Quality analysis tools like coding convention checkers or our assessment toolkit CONQAT [7] report their results with respect to the entities defined in the model. Hence, the quality engineer

can give concrete instructions to developers to correct quality issues. The results of quality analysis tools that require the execution of the system, e.g. usability tests, do usually not provide such a direct relation to the entities. However, the model supports the identification of entities responsible for quality defects via the explicitly stored relations between entities and activities.

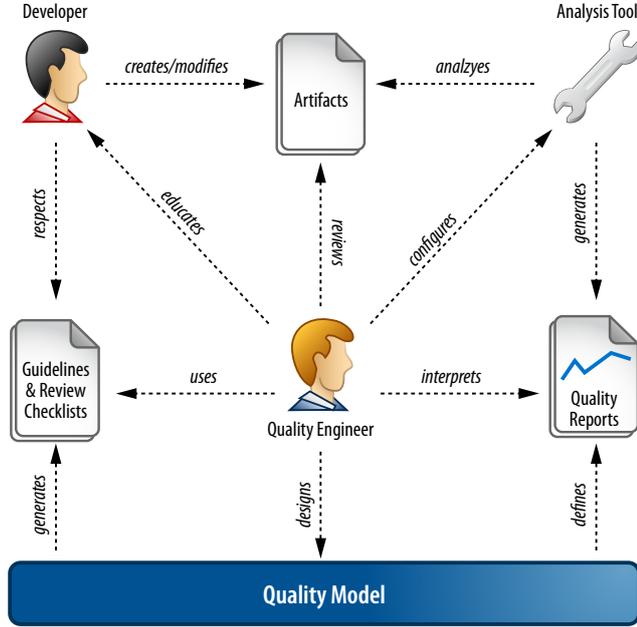


Figure 3: Model-based quality assurance

6. CASE STUDY

We show the applicability of our approach in an automotive case study. DaimlerChrysler published a sample system specification of an instrument cluster [5]. The instrument cluster is the system behind a vehicle’s dashboard controlling the rev meter, the speedometer, indicator lights, etc. The specification is strongly focused on functional requirements but also contains various “business” requirements that consider quality aspects. The functional requirements are analysed in more detail in [18]. We mainly look at the software requirements but also at how the software influences the hardware requirements.

6.1 Identifying Relevant Stakeholders

We can identify two stakeholders for the quality requirements stated in [5]. The relevant requirements are mainly concerned with the user of the system, i.e., the *driver*. He needs to have a good view on all information, relevant information needs to be given directly and his safety has to be ensured. To derive the corresponding activities, we can use the quality model for usability described in [25]. It contains a case study about the ISO 15005 [16] that defines ergonomic principles for the design of transport information and control systems (TICS). The instrument cluster is one example of such systems. Hence, the identified activities can be used here. The distinction on the top level is in *driving* and *TICS dialog*. The former describes the activity of controlling the car in order to navigate and manoeuvre it.

Examples are steering, braking, or accelerating. The latter means the actual use of a TICS system. It is divided into: (1) *view*, (2) *perception*, (3) *processing*, and (4) *input*. This level of granularity is sufficient to describe quality related relationships [25].

The second important stakeholder is the manufacturer of the vehicle, the *OEM*. The concern is mainly in two directions: (1) reuse of proven hardware from the last series and (2) power consumption. The former is an OEM concern because it allows decreased costs and ensures a certain level of reliability which in turn also reduces costs by less defect fixes. The power consumption is typically an important topic in automotive development because of the high amount of electronic equipment that needs to be served. Hence, to avoid a larger or a second battery – and thereby higher costs –, the power consumption has to be minimised. Therefore, the relevant activities of the OEM are (1) *system integration* in which the software is integrated with the hardware and (2) *defect correction* which includes callbacks as well as repairs because of warranty.

6.2 Ranking Activities

The above identified activities of the two relevant stakeholders need now be ranked according to their importance for those stakeholders. The decisive view is obviously the one from the payer, in this case the *OEM*. Only legal constraints can have a higher priority.

Although we do not know how DaimlerChrysler would prioritise these activities, we assume that usually the safety of the driver should have the highest priority. Hence, the *driving* activity is ranked above *defect correction* and *system integration*. The rationale for ranking *defect correction* higher than *system integration* is that the former is extremely expensive, especially in case the system is in the field already. This is partly backed up by the commonly known fact that it is more expensive to fix a defect, the later it is detected [24]. The complete ranking is also shown in Tab. 1.

6.3 Defining Requirements Qualitatively

Having identified and prioritised the activities that are performed on and with the system, they can be used to define the requirements qualitatively. This way, the requirements are elicited and some requirements may not be possible to give in finer detail. For the case study, we analyse the “business requirements” and their rationales (if available) from [5] to derive qualitative ratings. The ratings for the activities are summarised in Tab. 1.

Table 1: Qualitatively defined requirements for the prioritised activities

Activity	Rating
Driving	comfortable, safe, not distracted
TICS Dialog	informative, attractive, correct, current, agile, dynamic, safe, reliable, traditional, accurate, authentic, intuitive, improved
Defect correction	minimal
System integration	minimal hardware requirements, using existing hardware components, interoperable with different hardware

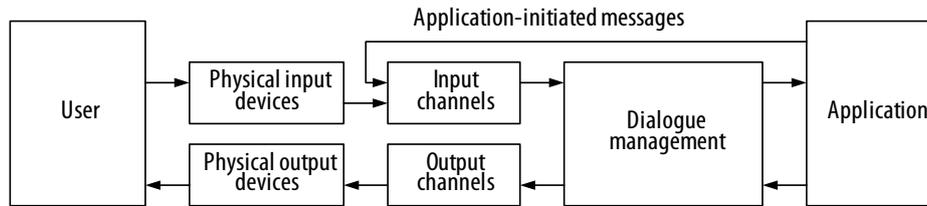


Figure 4: The abstract user interface architecture

For all parts of the instrument cluster, it is wanted that *driving* is still comfortable. The *driver* should not be distracted in the *driving* activity. Hence, it must be safe. The most information can not surprisingly be found about the *TICS dialog* itself. It is often stated that it should be possible to obtain information and that the dialog should be attractive for the *driver*. The information displayed needs to be correct, current, accurate, and authentic. In general, it is also stated that the dialog needs to be “well-known” what we called “traditional” but it must also improve over the current systems. The *defect correction* should be minimal with a high robustness and life-span. Finally, *system integration* should have minimal hardware requirements and use existing hardware components. It should also be able to use different hardware, especially in the case of different radio vendors.

6.4 Refining Using Entities Tree

We can again use the quality model from [25] for most of the entities tree. It provides a decomposition of the *vehicle* into the *driver* and *TICS*. The *TICS* is further divided into *hardware* and *software*. The software is decomposed based on an abstract architecture of user interfaces from [25] as depicted in Fig. 4. The hardware is divided into operating devices, indicators/display, and the actual *TICS* unit.

The quality model gives us also the connection from activities to those entities. It shows which entities need to be considered w.r.t. the activities of the stakeholders that are important for our instrument cluster. We cannot describe this completely for reasons of brevity but give some examples for refinements using the entities tree.

For the *driving* activity, we have a documented influence from the the hardware, for example. More specifically, the appropriateness of the position of the display has an influence on *driving*. In our more formal notation that is:

$$[\text{Display.Position} \mid \text{APPROPRIATENESS}] \xrightarrow{+} [\text{Driving}]$$

Hence, in order to reach the qualitative goals for the *driving* activity, we need to ensure that the display position is appropriate.

A second example starts from the *processing* activity. It is influenced by the unambiguousness of the representation of the output data:

$$[\text{OutputData.Representation} \mid \text{UNAMBIGUOUSNESS}] \xrightarrow{+} [\text{TICSdialog.Processing}]$$

Therefore, we have a requirement on the representation of the output data that it must be unambiguous, i.e., the driver understands the priority of the information.

Finally, *perception* is an activity in the *TICS dialog* that is influenced by the adaptability of the output data representation:

$$[\text{OutputData.Representation} \mid \text{ADAPTABILITY}] \xrightarrow{+} [\text{TICSdialog.Perception}]$$

The representation should be adapted to different driving situations so that the time for *perception* is minimised. Such a requirement is currently missing in the specification [5].

6.5 Quantifying Requirements

For the quantification of the requirements, the quality model can only help if there are metrics defined for measuring the facts. Then an appropriate value can be defined for that metric. Otherwise, the model must be extended here with a metric, if possible. We can again not describe all necessary quantifications of the instrument cluster specification but provide some examples.

The above identified requirement about the appropriateness of the display position can be given a quantification. The specification [5] actually demands that “The display tolerance [...] amounts to ± 1.5 degrees.” Furthermore, it is stated that “The angle of deflection of the pointer of the rev meter display amounts to 162 degrees.”

The example of the unambiguous representation of the output data cannot be described with some kind of numerical value. However, the specification [5] demands that the engine control light must not be placed in the digital display with lots of other information “because an own place in the instrument cluster increases its importance”.

6.6 Discussion

For reasons of brevity, we are not able to describe the whole quality requirements elicitation and refinement for the instrument cluster. However, the examples show that our approach is applicable to such an automotive system. We observed that we have a clear guidance in eliciting and refining the requirements along the quality model. Starting from the stakeholders, their activities down to the influencing system entities is a straight-forward thinking process. Moreover, we found that several of the informations needed during the application of our approach was already contained in the specification but not consistently for all its parts. Finally, we also noted that we were able to identify several requirements that were not considered in the specification that can have an influence on the relevant activities.

7. CONCLUSIONS

Although it has been acknowledged that quality requirements are difficult to handle and that they often have been

neglected, a well-founded and agreed structuring of those requirements has not been established. In some way, most classifications are related to the ISO 9126 standard [17] that, however, does not consider the various activities of the stakeholders. Our unique, two-dimensional quality model [8] resolves this problem by explicitly modelling the influences of entities on activities. Using the activities of the stakeholders and following these impacts in the opposite direction, we can employ a structured and well-founded process to elicit and refine the quality requirements.

Moreover, there is a direct connection and traceability to the quality assurance techniques used in the project. Those techniques are responsible for assuring that the quality requirements have been fulfilled. The quality model serves as a basis of the quality assurance and thereby allows to relate the results to the requirements.

The applicability of the approach was shown in a case study based on a published instrument cluster specification of DaimlerChrysler. We were able to show that the approach allows a structured elicitation and refinement of quality requirements using the activities of the stakeholders and their relationships with entities in the system that are documented in a quality model. We found information that could be fitted into our approach but also could identify omissions in the specification.

We plan to develop the approach in more detail and to validate it in more case studies. Moreover, the quality model itself is continuously extended and improved. This in turn also amends the quality requirements approach.

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