Martin Beckmann, Christian Reuter, Andreas Vogelsang

Coexisting graphical and structured textual representations of requirements

insights and suggestions

Coexisting Graphical and Structured Textual Representations of Requirements: Insights and Suggestions

Martin Beckmann[1], Christian Reuter[2], and Andreas Vogelsang[1]

[1] Technische Universität Berlin, Germany
[2] Daimler AG, Germany

Abstract. [**Context & motivation**] Many requirements documents contain graphical and textual representations of requirements side-by-side. These representations may be complementary but oftentimes they are strongly related or even express the same content. [**Question/problem**] Since both representation may be used on their own, we want to find out why and how a combination of them is used in practice. In consequence, we want to know what advantages such an approach provides and whether challenges arise from the coexistence. [**Principal ideas/results**] To get more insights into how graphical and textual representations are used in requirements documents, we conducted eight interviews with stakeholders at Daimler. These stakeholders work on a system that is specified by tabular textual descriptions and UML activity diagrams. The results indicate that the different representations are associated with different activities. [**Contribution**] Our study provides insights into a possible implementation of a specification approach using mixed representations of requirements. We use these insights to make suggestions on how to apply the approach in a way that profits from its advantages and mitigates potential weaknesses. While we draw our conclusions from a single use case, some aspects might be applicable in general.

Keywords: Model-Driven Software Specification; Graphical Models; Requirements Documents; UML Activity Diagram

1 Introduction

Eliciting and specifying requirements by means of models is becoming more and more popular in the development of complex embedded systems [1]. However, these models usually accompany and complement textual requirements and do not replace them. Therefore, many requirements documents contain graphical and textual representations of requirements side-by-side. This combined use of graphical diagrams and textual descriptions is considered beneficial for the requirements management process [2, 3].

In practice, there are more substantial reasons why the same information may be expressed in a graphical model and also in an accompanying text. For example, industrial applications, tool support, and model exchange for graphical models are still not standardized [4] and, as a result, manufacturer/supplier handover is still performed by textual documents. This is especially important, since these textual documents often serve as the basis for legal considerations between the contractors [3, 5]. Also, due to different backgrounds of the stakeholders, not everyone is capable of understanding the graphical models [6].

Maintaining and updating information in graphical and textual representations is often performed manually. In previous work, we have shown that this is a potential source for inconsistencies and quality issues in the requirements specifications [7]. Moreover, best practices and guidelines for when and how to use graphical or textual representations are missing. This leads to discussions about the validity of the representations, when deviating representations exist.

Without a deeper understanding of how the different representations are used and why they coexist, it is hard to come up with measures for ensuring consistency or to decide how content should be represented. Therefore, we are interested in how coexisting graphical and textual representations of requirements are used by stakeholders of the system. For this purpose we considered one particular instance of this case in practice, where a team at Daimler uses UML Activity Diagrams to provide a high-level overview of the activation conditions for a vehicle function. The information contained in this model is afterwards transferred into a tabular textual representation that is then further detailed.

We conducted eight interviews with practitioners at Daimler. Three interviewees have developed the specification approach described above. Five interviewees work with the resulting requirements document. From these interviews, we derive a model that describes for which activities stakeholders use graphical or textual representations. Also, we use the acquired data to provide suggestions on how graphical and textual representations should be used to leverage their potential and avoid pitfalls which would lead to quality issues.

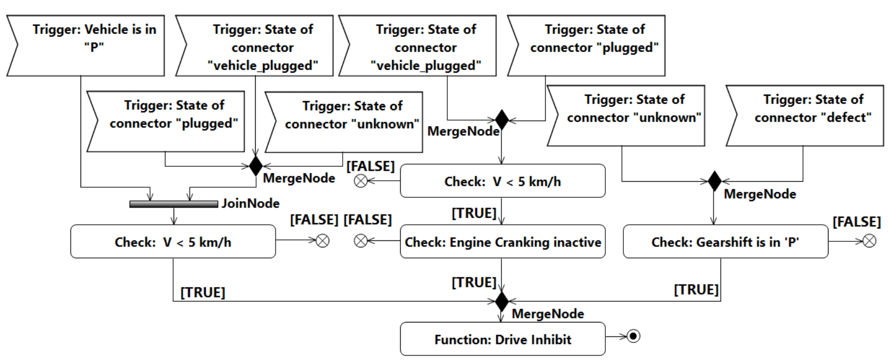

Fig. 1: Activity diagram of the function *Drive Inhibit*

2 Background

A team at Daimler employs UML activity diagrams [8] to specify functions of a system. The diagrams are used to get an early overview of the desired function behavior with a special focus on the activation of the function, execution conditions, functional paths, and deactivation. Fig. 1 depicts a diagram of the system. The actual behavior of the activated function is described in the *Action* node labeled with *Drive Inhibit* (bottom of the diagram). The activation of the function is described by a combination of triggers and checks for conditions. This pattern to describe functions is also known for building textual requirements [9]. Activity diagrams are interpreted according to the requirements-level semantics of activities as defined by Eshuis and Wieringa [10]. As such, we assume that each node executes as soon as a token is placed on that node (by a transition or by occurrence of events). We also assume that the time required to execute a node is infinitely short. Control nodes have the usual semantics: *MergeNodes* (diamonds) and *JoinNodes* (bars) represent OR connections and AND connections, respectively. All the activity diagrams of the system are modeled in a similar way in regard to the used pattern, structure and layout.

The activity diagrams are then embedded in a textual requirements specification in two representations: (a) graphically as an image, (b) in a tabular, textual form which is supposed to reflect the same behavior as the activity diagram. The tabular representations may be refined and extended later.

Fig. 2 shows the textual representation of the activity diagram in Fig. 1 as we found it in the specification document of our industry partner. The basic idea of the textual representation is to represent the triggers and checking conditions which govern the execution of a function as a kind of AND-OR table with postfix boolean operators. As such, the textual representation emphasizes the propositional logic aspect of the behavior. Each row represents an object, which is described by a set of attributes (columns). These attributes are needed to display the relevant information of the activity diagram in the requirements document. The *ID* attribute contains a unique identifier of the object. The *Text* attribute is a textual description of the object and is supposed to be equal to the text of the corresponding element in the activity diagram. It also contains the boolean operators which connect multiple elements within a cell or connect one row to the next row on the same *Level*. The *Level* is an attribute to structure the objects hierarchically. It is derived from the structure of the activity diagram. The *Type* attribute denotes whether an object is a function, a trigger or a condition to be checked. The object types in the table are derived from the types of the corresponding elements in the activity diagram.

Note that the activity diagram and the textual representation exhibit a number of differences with respect to both placement of elements and the specified behavior. E.g., the element *Check: Engine Cranking inactive* has the predecessor *Check: V < 5 km/h* in the activity diagram, while in the textual representation the element *Vehicle Gear selector is in position "P"* is the predecessor. Besides, some rows in the textual representation mistakenly have a connector at their end (*ID 1113*, *1233*), although there are no further rows on the same *Level*.

These issues may originate from the manual generation of the textual representation and changes over time. We have addressed these problems in a previous paper [7].

ID	Text	Level	Type
1000	**1.1.1.1.1.1 Drive Inhibit**	6	Function
1236	State of connector "unknown" OR State of connector "defect" OR	7	Trigger
1237	Vehicle Gear selector is in position "P" AND	8	Check
1113	Engine Cranking inactive OR	8	Check
1111	State of connector "plugged on vehicle side" ("VEH_PLUGGED") OR "plugged on vehicle and EVSE side" ("PLUGGED") OR	7	Trigger
1112	Vehicle velocity is below 5 km/h	8	Check
1114	Vehicle Gear selector is in position "P" OR	7	Trigger
1232	Vehicle velocity is below 5 km/h	8	Check
1233	State of connector "plugged on vehicle side" OR State of connector "plugged on vehicle and EVSE side" OR State of connector "unknown" AND	7	Trigger
1238	Vehicle velocity is below 5 km/h	8	Check

Fig. 2: Textual representation of the function *Drive Inhibit*

The sample in Fig. 2 only depicts the contents derived from the activity. Besides the mentioned attributes, the document may contain other attributes used for further development. Also, the textual document may contain more detailed information in the form of further requirements and descriptions. These entries may be both formal (e.g., parameter values) and in freely-written natural language.

3 Related Work

Graphical notations as a means to ease the understanding of complex systems have been used in different contexts [11, 12]. Nevertheless, despite showing several advantages there are drawbacks such as end users' unfamiliarity with graphical notations and limits on the displayable details in visualizations. Moreover in requirements engineering, research has identified the need for different representations of requirements [13]. A possibility to tackle these issues is to use accompanying text for graphical models. Arlow et. al. introduced an approach called *Literate Modelling* that works with this idea and employs UML models as the graphical models [6]. This concept of coexisting graphical models and textual descriptions was picked up and discussed for future tools in requirements engineering [14]. In addition the approach is supported by ideas using a graphical model as a basis to generate a structure for requirements documents and requirements itself [15].

However, to the best of our knowledge, there is only a small number of works on the topic of how to apply the approach and on its impact. Aside from computer science, it has been shown that the combined use of words (written and spoken) and pictures has a beneficial effect on a person's perception [16]. Still, it is also known that readers focus on the representation that takes the least effort to understand, in case they contain the same information [17].

A study of Burton-Jones et. al. with student participants investigates whether a combination of representations is beneficial [18]. They report a positive impact for understanding a new system by using conceptual graphical models and a textual narrative, but do not give details on how to implement such an approach in practice. Our intent is to improve the understanding in this area by interviewing practitioners and to make suggestions on how to implement such a mixed representation approach in the best way possible.

4 Study Design

To gain a better understanding of how the approach is used and how the involved parties work with the activity diagrams and the textual parts, we conducted an interview study with stakeholders of one particular system. We designed the study along the recommendations of Runeson and Höst [19].

Research Objective: We want to know how the different stakeholders use the graphical models and the textual descriptions, how and where they make changes, and how they ensure consistency of the specification. Additionally, we are interested in the stakeholder's perception of advantages, challenges, and best practices of the application of the approach.

To reach this objective, we pursue three research questions (RQ):

RQ1: For which activities do the stakeholders use which representation? With this research question, we aim at getting insights about the use of different representations in order to be able to derive suggestions for working in a setting with coexisting representations.

RQ2: What are the reasons why stakeholders use one or the other representation for specific tasks? We want to find out why stakeholders use one of the representations for certain tasks. This is meant to provide insights on the benefits the graphical models offer and how the coexisting artifacts are used in the work of the involved persons.

RQ3: What challenges arise in the combined use of graphical models and text and how should they be addressed? We want to know what problems the stakeholders face. This gives us an idea on potentials for improvement. Also, this RQ is used to derive suggestions for the use of graphical models in combination with text for specifying functions.

Study Object: We conducted this study in the context of the development of one particular system. The system contains functions involved with charging the batteries of Plug-in Hybrid Electric Vehicles and Battery Electric Vehicles.

As such, the system contains requirements that are relevant for safety as well as for usability. Overall, there are 14 functions in the system which are described by the approach mentioned in section 2. These functions contain a total of 22 activity diagrams and almost 2,000 objects (including requirements, descriptions and headings). The additional activity diagrams result from the fact that some subfunctions of the functions are also described by activity diagrams and text.

Data Collection: We conducted interviews with eight stakeholders of one particular system. The majority of the interviewed stakeholders (five) either depend on the contents of the requirements document directly or on content which is derived thereof automatically or manually. The rest of the stakeholders (three) are concerned with the methods that are applied to specify systems and components at Daimler. We group the participants into three groups: those involved with the testing of the functions (in the following referred to by: T_1, T_2), those who use the specified functions to specify components (C_1, C_2, C_3), and those developing the applied methods (M_1, M_2, M_3).

The interviews were performed by following an interview guideline. The interview guideline was created in multiple iterations. In each iteration the structure and questions were refined by discussions with other researchers and practitioners of our industry partner to ensure that the research questions are properly addressed. However, the interviews were conducted as open interviews. In case the participants mentioned issues aside from the questions of the guideline, we did not interrupt and followed up on these issues in some cases. Also, insights gained during the interviews were considered in the following interviews.

The first part of each interview concerned the background of the interviewee. We asked questions on how long they have been working with the contents of the system, what their current role is, whether there was prior knowledge in dealing with graphical models, and what their general attitude is towards the use of graphical models.

The second part aimed at eliciting facts about their work. This question covered what the participants actually use the activity or text for as well as in what way the two artifacts provide different information for their tasks. Furthermore, we asked what purposes the activity diagram and the textual description respectively fulfill. As the participants M_1, M_2 and M_3 do not directly work on the contents we engaged them in a discussion about their idea how the artifacts are supposed to be used. In addition, we asked the participants for their general impression on the quality of the activity diagrams and the accompanying text.

The third part aimed at initiating a discussion with the participants. We wanted to know where they see advantages in the current approach, what challenges they face in applying it in their own work and how to possibly deal with them. We also wanted to find out how they perceive the influence of the approach on the contents they are provided with. Hence, we encouraged the participants to give their opinion on the way the system's functions are specified and what consequences they expect for their tasks. Furthermore, we wanted to find out whether they can imagine a different process for the specification of functions and how that would differ from the current approach.

The majority of the interviews (five) was conducted on site. The rest of the interviews (three) was conducted by telephone. We ensured that the statements of the participants were handled in an anonymous way to guarantee honest answers. The interviews were scheduled to last about an hour. In the end the shortest interview lasted 32 minutes, while the longest took almost 90 minutes. The interviews were recorded.

Data Analysis: The first author created transcripts of the interviews. These transcripts summarize the whole interview and contain the essential statements of the participants. Due to the open nature of the interviews the number of statements differ from participant to participant. We analyzed the transcripts by applying qualitative coding [20]. The analysis was performed by the first and the second author. Our first step was to read the interview transcripts to get an overall impression. This impression was used to extract a first set of concepts. These concepts were then discussed in regard to their relevance towards the research questions. The discussion resulted in a common set of concepts. We then checked the transcripts for information, which fit the identified concepts. This task was performed independently and afterwards the coding was compared. In case of deviations the results were discussed until we reached a mutual agreement. This mutual agreement led to the omission of a number of statements, since they did not directly address the research questions. It turned out that some of these omitted statements covered interesting aspects nonetheless. Hence, it was decided to repeat the process in the same manner with additional concepts in order to include these aspects. We deduced the relevance of these aspects by the fact that they were mentioned by multiple participants.

5 Study Results

5.1 Demographics & Background

The interviewed participants have been working for our industry partner for a time period between 2 and 28 years. All of the participants stated to have prior experience in working with graphical models. This encompassed statements between some familiarity with UML and similar graphical notations to expert knowledge in the application of graphical models in the development of systems. Also, all participants stated to have a positive attitude towards the use of graphical models. Those statements ranged between seeing minor benefits to the impression that graphical models are nowadays necessary to be able to comply with standards and to create high-quality requirements.

5.2 Benefits & Use of the Approach

To address RQ1 and RQ2, we considered the answers to the questions that concerned the activities the participants perform during their work as well as parts of the discussion revolving around the advantages they perceive.

The tasks the participants perform are shown in Fig. 3. Boxes denote activities, while ovals represent artifacts. The lines show the associations that the participants mentioned in the interviews. The arrow between the two artifacts indicates that the graphical model is the initial artifact which is used to derive the textual descriptions.

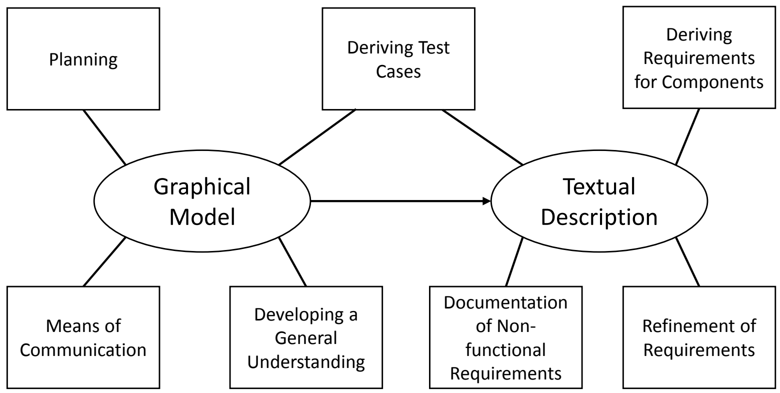

Fig. 3: Tasks associated with the artifacts

To use the graphical models as a means of communication and to develop a general understanding was identified as a task by almost all participants. Additionally, two participants (M_1, M_3) mentioned to use the graphical model during release planning. They use the relations between the elements of the diagram to gain insights into dependencies between underlying components, which in turn facilitates the planning. The only task associated with both representations is deriving test cases. In this matter, participant T_2 explicitly mentioned that the activity diagrams are the actual basis to create some of the test cases and not just a supporting alternative view of the text.

Nevertheless, the groups involved in testing and those responsible for components of the system both stated to rely mostly or even solely on the textual description to derive their own artifacts (test cases and components requirements). Furthermore the textual description was mentioned to be used to refine requirements and to provide more details on contexts and surrounding circumstances by all of the participants.

Aside from the performed activities, there seems to be confusion about the use of the approach itself. There was no common understanding between the participants on whether the textual or the graphical representation should be created first, which one is used in case of inconsistencies, and where changes are incorporated. Different statements were made on this topic. Some participants mentioned that they are unaware of how the artifacts are created and where to incorporate changes.

Moreover, the answers of the participants offered insights on what they think the artifacts are used for and what benefits the approach offers. Table 1 and Table 2 show an overview of all statements the participants made about graphical models and textual descriptions, respectively. A ✓ denotes that the participant made that statement while a – denotes that the participants did not make mention of that fact.

Since all participants mentioned to have a positive attitude towards the use of graphical models, it is not surprising that their use is considered beneficial. Many even mentioned that they consider the use of graphical models as a necessity. As the associated tasks have shown, there is a lot of agreement that activity diagrams are used as a means of communication and a basis for discussion. Also, it was mentioned explicitly by almost all participants that the diagram improves the general understanding of a function.

For the textual descriptions, most participants mentioned that they see the text as the reference and it is used to provide details. The fact that the text is necessary because of legal considerations was only mentioned explicitly by participant T_2. The necessity to support stakeholders who are unfamiliar with the use of graphical models was stated by C_1, T_2 and M_2.

5.3 Challenges & Possible Improvements

To answer RQ3, we asked how they perceive the quality of the activity diagrams and their textual representation. More specifically, we wanted to know how they like the way the artifacts are structured and whether they face challenges by maintaining coexisting artifacts.

All participants emphasized that consistency is a major problem in the way the approach is currently applied. As a consequence, all participants would appreciate automatic support for deriving the textual description from the activity diagrams. They assume that this would have a positive impact on their work.

The textual representation was criticized with regard to its interpretation. Some participants said that they would prefer a different structure as the current one is not intuitively understandable. However, further inquiries on this issue revealed that the boolean operators without following rows on the same level (described in section 2) are not perceived as a problem.

Many issues with the activity diagrams were mentioned. For instance, critique was expressed on the depiction of the activity diagrams. This critique focused most often on the fact that the diagrams are not uniformly designed using the same tool. Also, the pattern depicted in Fig. 1 is not strictly enforced. Furthermore, the contained information was criticized in regard to both the amount and level of detail. This point encompassed different opinions of the participants. Some of them stated that required information, such as signal names and values, are missing in the diagrams. Others stated that there are too many elements and details in some diagrams to understand a function properly. Yet, others said that the activity diagrams contain information (e.g., of other components) that is not relevant for them.

As the layout of a graphical model has a major impact on its understandability [21], we also wanted an opinion on the quality of the layout. All of the participants mentioned to be satisfied with the quality in that regard. Still, the way the activity diagrams are embedded in the tool was criticized. The diagram

Table 1: Statements about the use of graphical models by participants

Participant	considered beneficial	considered necessary	means of communication / discussion	improves understandability	should be basis for text	display architecture	represents relations	used for planning
C_1	✓	–	✓	✓	✓	✓	✓	–
C_2	✓	–	✓	✓	✓	–	✓	–
C_3	✓	–	✓	✓	✓	✓	✓	–
T_1	✓	–	✓	✓	✓	–	✓	–
T_2	–	✓	–	–	✓	–	–	–
M_1	–	✓	–	✓	–	✓	✓	✓
M_2	–	✓	✓	✓	✓	✓	✓	–
M_3	–	✓	✓	✓	–	–	✓	✓

Table 2: Statements about textual descriptions by participants

Participant	acts as reference	legal considerations	contains details	handover for supplier	used for non-functional requirements	support stakeholders unfamiliar with models
C_1	✓	–	✓	–	–	✓
C_2	✓	–	✓	–	–	–
C_3	✓	–	✓	✓	–	–
T_1	✓	–	–	–	–	–
T_2	–	✓	✓	✓	–	✓
M_1	–	–	✓	✓	–	–
M_2	–	–	✓	✓	✓	✓
M_3	–	–	✓	–	–	✓

is included as a picture in a cell in the requirements document. Since the default size of such a cell does not allow for the display of the complete diagram, it is necessary to adjust its size manually in order to see the full diagram.

5.4 Beyond the Research Questions

Since we designed the study as an open interview, many things were mentioned that did not directly address our research questions. Still, some of these statements are within the scope of our research objective.

Regarding the question what the graphical model is used for, the answer that appeared most often was an improved understandability. Further questions in that matter revealed that the understanding concerns mostly relations between the elements in the graphical representation. Aspects of activities such as independent executability of actions and asynchronous behavior were never mentioned. When we specifically asked for that, it was stated, that this is of no importance on that level of description.

As the automated generation of the textual description from the graphical models was mentioned, we wanted to know whether the capability of synchronization of the graphical and textual representation is needed. The participants answered that this capability would be nice-to-have, but all agreed that changes are best incorporated in the graphical model. M_1, C_2 and T_2 said, it should not be possible to change aspects of the graphical model in its textual description and hence a synchronization in the backwards direction should not be allowed.

Towards the end of the interviews, we challenged the approach as a whole and asked whether they could work without the textual representation. Because of the already mentioned uses of the text, about half the participants instantly stated that it does not seem possible. The rest was open to the idea, but had doubts, because of organizational considerations (e.g., handover to suppliers, legal issues) and also stated the necessary models would mitigate their main advantage — the capability of offering a clear overview. Participant T_2 said this would require major modifications in the company structure. It would be possible if all development tasks from suppliers are reintegrated to one place.

6 Discussion

6.1 Findings from our Study

All in all, there seems to be a common understanding between the different stakeholders on why they use this approach and on what to use each artifact for. We derive this conclusion from the fact that all of the stakeholders consider the two coexisting artifacts to be at least beneficial. This is also reflected by the fact that there is a high-level of agreement towards the way the respective artifacts are used. Furthermore, the association of specific tasks with certain artifacts indicates that both the graphical representation and the textual representation are necessary to manage the complexity of today's systems and hence create high-quality requirements specifications.

The graphical representation is mainly seen as a means of communication and discussion and for improved understandability by almost all participants. Communication and discussions are necessary to make sure the behavior is as originally intended. A proper understanding of the function is mandatory for the stakeholders. These two purposes facilitate subsequent tasks such as deriving requirements for components and the manual generation of test cases. Thus, we see the diagram in a rather supportive role. These results also indicate that the graphic models are primarily used for the purpose of visualization and not for expressing precise semantics. In consequence it serves a wallpaper use [22].

The only aspect that was commented conflictingly about the graphical models regarded their depiction. Participant T_1 mentioned, that she would rather prefer more elements in a diagram than scrolling to a different diagram to get more information. Participant T_2 mentioned that the maximum number of elements in a diagram should be restricted to about seven elements and, if further elements are required, they should be nested into a linked diagram. In addition, some participants complained about information in the diagrams that is not relevant to them. This conflict cannot be resolved by using a single graphical representation of a function for all stakeholders (cf. [13]).

As for the textual representation, the results strongly suggest that it is in fact the preferable medium to accommodate refinements and details. Half of the participants mentioned the need to support stakeholders unfamiliar with graphic models. This is an issue that constantly appears in contexts where models are used. The coexistence of textual descriptions and graphical models appears to be a possible solution to this issue [23]. Nevertheless, there might be more fitting possibilities to arrange the textual representation than the one currently used (see [24] for a study on different textual representations of activity diagrams).

Although the graphical representation is created as a first step for the specification, its use is not restricted to the specification phase. As our participants perform a variety of tasks, we found out that the graphical model fulfills more purposes than just being a starting point for further specification. Amongst others it is used to derive test cases and to support understanding of the intended behavior. Hence, it proved to have been a good idea to consider participants outside the group of people who create the graphical models and textual descriptions. This selection of participants, on the other hand, also explains the lack of understanding which artifact is created at which step in the process, where changes are incorporated, and which artifact has to be used in case of inconsistencies. In hindsight, it turned out that the lack of a definition which artifact is used as the lead is also linked to the study object. Although half of the participants mentioned that the text is used as a handover and for legal considerations, this mainly applies to the derived component specifications. System specifications are mainly used internally and hence using the textual representation as the reference is not strictly enforced.

With regard to these insights we conclude that in our case using a textual and graphical representation on the same level of abstraction is an appropriate means in the development of systems since the artifacts serve different purposes.

To make the most of the approach, we make suggestions that aim at mitigating the found weaknesses and taking advantages of the identified strengths.

6.2 Suggestions

Based on the insights we make suggestions on how to implement a mixed representations approach in order to leverage the potentials of the respective representations. From the high level of agreement concerning that the activity diagram should be used as a basis for the text, we conclude that the activity diagram is indeed an adequate starting point for the specification process of our industry partner. This finding is largely in line with research on the use of graphical models that emphasizes its use during the early stages of development [25]. Hence, this section starts with suggestions on the use of the activity diagrams and proceeds with suggestions on the textual representation of our industry partner.

Use of the Activity Diagrams. One of the major factors to the success of graphical models is that it needs to be understood by as many stakeholders as possible. To achieve this, it is paramount to design the models according to a defined pattern. Also, we recommend to use a common tool for the modeling in order to ensure a uniform look, although this might be hard to enforce. Nevertheless, access to the tool should be granted to all who make use of the activity diagram. This is required to address the problem with the handling of the diagram. From the different opinions on the contained information, we conclude that a mechanism is needed to tailor the models according to each individual's needs. This suggestion has been stated before [13] and is in line with established solutions on using textual requirements [26].

Use of the Text. Deriving the text from the activity diagram avoids inconsistencies and hence ensures that the same behavior is described by both representations. Aside from the situation of our industry partner, there are already a number of approaches dealing with the generation of requirements specifications (or parts thereof) from models [15]. Following our participants the text can be used to incorporate refinements and details. As the complementary information may also be freely written in natural language, this representation may in fact be better suited for stakeholders unfamiliar with the notations of activities. Detailed information should only appear in the text to avoid further consistency issues and to guarantee the main purpose of the activity diagram is not impaired — to maintain a high-level overview.

Incorporation of Changes. As the appearance of changes is inevitable in the course of development, their incorporation in the artifacts must be considered. Changes to the relations of entities are easier to implement in the diagram. For textual changes it does not make much difference which representation is used. Nevertheless, to avoid inconsistencies only a single artifact should be used.

Hence, the activity diagram should accommodate changes which affect both representations, although this might be hard to realize considering the fact that multiple persons work with the specification artifacts. The changes in the activity diagram are then propagated to the textual representation. It has to be noted that the additional textual content is not deleted or modified in the process.

Alternatively, changes could be automatically incorporated by using tools such as Projectional Editors, which automatically edit different projections of a common underlying model, in this case the activity diagram and its textual representation. However, this approach requires substantial efforts and accordingly trained developers [27]. Hence, a custom-made and lightweight solution to generate and update the textual representation might be better suited for the situation of our industry partner.

Further Related Tasks. As for the tasks of the respective artifacts, the situation displayed in Fig. 3 is already a good way of applying the strengths of the model and the text. The main concern of the graphical model is human-based analysis and the exchange of ideas between stakeholders. As such, the tasks of planning, improving understanding, and facilitating communication are prone to involve a visualization. Still, since the graphical representation provides a high-level overview, these tasks are restricted to early stages of development, when the required descriptions do not need to be detailed. Nonetheless, the defined syntax and semantics of a graphical model can also be used to automatically derive test cases [28].

6.3 Threats to Validity

The participating stakeholders were selected by the second author who is also actively participating in the development of the examined system. We did not follow specific selection criteria, except that participants must work actively on the examined system. However, the group of study participants only represent a subset of all people working actively with the requirements documents.

Furthermore we only had access to internal participants within one company. However, the activity diagrams and their textual descriptions must also be read and understood outside the company, such as legal authorities and suppliers. Their opinion is critical since inquiries on unclear issues require more effort between multiple organizations than inside a single company.

Also, our study examined the present situation of an approach using activity diagrams. The use of other graphical models might influence the proposed suggestions as well as the benefits and weaknesses we identified.

To answer our research questions, we only had access to a limited number of participants who actively work with this approach or are responsible for the applied methods. Also, we only gained insights into a single implementation of a mixed representation approach which uses activity diagrams and a very specific kind of textual representation. In conclusion, although our findings turned out to be consistent, our results can only be seen as a first step. Hence, further research is required to generalize our findings.

7 Conclusion and Future Work

In this paper, we present the results of a number of interviews we conducted to gain a better understanding of a specification approach that uses coexisting activity diagrams and tabular textual descriptions. The results incorporate an assessment of our participants on which artifact is suitable for which task as well as their opinion on the benefits of the respective artifacts. The use of graphical models for themselves as well as their use in coexistence with textual description on the same level of abstraction is perceived as beneficial. We use the insights gained by these results to derive suggestions. The suggestions serve the purpose of providing a guideline on how to implement such an approach in order to avoid inconsistencies and leverage its full potential.

Although we think that our results can be generally applied to approaches using coexisting graphical and textual artifacts, the results should be further validated by repeating the study with differing implementations of the approach. The differences might concern the type of graphical model and the pattern for textual description. Also, the extent to which practitioners benefit from our suggestions needs to be further examined. Moreover, the graphical and textual representations described in this paper are not the only artifacts. To handle the complexity of today's systems, further diagrams and associated documents might be needed. Ensuring the propagation of necessary changes to these artifacts is still not implemented in an acceptable manner and hence needs further investigation.

References

1. Broy, M.: Challenges in automotive software engineering. In: International Conference on Software Engineering. (2006)
2. Davis, A.M.: Just Enough Requirements Management: Where Software Development Meets Marketing. Dorset House Publishing Co., Inc. (2005)
3. Sikora, E., Tenbergen, B., Pohl, K.: Industry needs and research directions in requirements engineering for embedded systems. Requirements Engineering **17**(1) (Mar 2012)
4. Reuter, C.: Variant Management as a Cross-Sectional Approach for a Continuous Systems Engineering Environment. In: Grazer Symposium Virtual Vehicle. (2015)
5. Maiden, N.A.M., Manning, S., Jones, S., Greenwood, J.: Generating requirements from systems models using patterns: a case study. Requirements Engineering **10**(4) (Nov 2005)
6. Arlow, J., Emmerich, W., Quinn, J.: Literate Modelling Capturing Business Knowledge with the UML. In: International Conference on the Unified Modeling Language. (1998)
7. Beckmann, M., Vogelsang, A., Reuter, C.: A Case Study on a Specification Approach using Activity Diagrams in Requirements Documents. In: International Requirements Engineering Conference. (2017)
8. Object Management Group (OMG): OMG Unified Modeling Language (OMG UML), Version 2.5. http://www.omg.org/spec/UML/2.5/ (2015)

9. Firesmith, D.: Generating Complete, Unambiguous, and Verifiable Requirements from Stories, Scenarios, and Use Cases. Journal of Object Technology **3** (11 2004)
10. Eshuis, R., Wieringa, R.: Tool Support for Verifying UML Activity Diagrams. IEEE Transactions on Software Engineering **30**(7) (2004)
11. Huff, A.S.: Mapping Strategic Thought. John Wiley & Sons Ltd (1990)
12. Pidd, M.: Tools for Thinking: Modelling in Management Science. 3rd edn. John Wiley & Sons Ltd (2009)
13. Gross, A., Doerr, J.: What You Need Is What You Get!: The Vision of View-Based Requirements Specifications. In: International Requirements Engineering Conference. (2012)
14. Finkelstein, A., Emmerich, W.: The future of requirements management tools. In: Information Systems in Public Administration and Law., Österreichische Computer Gesellschaft (2000)
15. Nicolás, J., Toval, A.: On the generation of requirements specifications from software engineering models: A systematic literature review. Information and Software Technology **51** (09 2009)
16. Mayer, R.E.: The Cambridge Handbook of Multimedia Learning. Cambridge University Press (2005)
17. Payne, J.W., Bettman, J.R., Johnson, E.J.: The Adaptive Decision Maker. Cambridge University Press (1993)
18. Burton-Jones, A., Meso, P.N.: The Effects of Decomposition Quality and Multiple Forms of Information on Novices' Understanding of a Domain from a Conceptual Model. Journal of the Association for Information Systems **9**(12) (2008)
19. Runeson, P., Höst, M.: Guidelines for conducting and reporting case study research in software engineering. Empirical Software Engineering **14**(2) (2009)
20. Adolph, S., Hall, W., Kruchten, P.: Using grounded theory to study the experience of software development. Empirical Software Engineering **16**(4) (Aug 2011)
21. Mendling, J., Reijers, H.A., Cardoso, J.: What makes process models understandable? In: Alonso G., Dadam P., Rosemann M. (eds) Business Process Management. BPM 2007. Lecture Notes in Computer Science, vol 4714 (2007)
22. Drusinsky, D.: From UML activity diagrams to specification requirements. In: International Conference on System of Systems Engineering. (2008)
23. van Oosterom, P., Lemmen, C., Ingvarsson, T., van der Molen, P., Ploeger, H., Quak, W., Stoter, J., Zevenbergen, J.: The core cadastral domain model. Computers, Environment and Urban Systems **30**(5) (2006)
24. Beckmann, M., Vogelsang, A.: What is a Good Textual Representation of Activity Diagrams in Requirements Documents? In: International Model-Driven Requirements Engineering Workshop. (2017)
25. Lindland, O.I., Sindre, G., Sølvberg, A.: Understanding quality in conceptual modeling. IEEE Software **11**(2) (March 1994)
26. Weber, M., Weisbrod, J.: Requirements Engineering in Automotive Development - Experiences and Challenges. In: Joint International Conference on Requirements Engineering. (2002)
27. Berger, T., Völter, M., Jensen, H.P., Dangprasert, T., Siegmund, J.: Efficiency of projectional editing: A controlled experiment. In: International Symposium on Foundations of Software Engineering (FSE). (2016)
28. Beckmann, M., Karbe, T., Vogelsang, A.: Information Extraction from High-Level Activity Diagrams to Support Development Tasks. In: International Conference on Model-Driven Engineering and Software Development. (2018)