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Model-Based Engineering for Embedded Systems in Practice

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Abstract

Model-Based Engineering (MBE) aims at increasing the effectiveness of engineering by using models as key artifacts in the development process. While empirical studies on the use and the effects of MBE in industry generally exist, there is only little work targeting the embedded systems domain. We contribute to the body of knowledge with a study on the use and the assessment of MBE in that particular domain. Therefore, we collected quantitative data from 112 subjects, mostly professionals working with MBE, with the goal to assess the current State of Practice and the challenges the embedded systems domain is facing. Of the 112 subjects, the majority are experienced with MBE, working at large companies in the automotive, avionics, or healthcare domains. Additionally, mainly OEMs and First-tier suppliers are represented in the study. Our main findings are that MBE is used by a majority of all participants in the embedded systems domain, mainly for simulation, code generation, and documentation. Reported positive effects of MBE are higher quality and improved reusability. Main shortcomings are interoperability difficulties between MBE tools, high training effort for developers and usability issues. The data also shows that there are no large differences between subgroups with respect to domains, position in the value chain, company size and product size.

1 Introduction

Developing embedded systems increases in complexity and effort. In order to be able to handle the challenges in systems development, appropriate approaches have to be applied. Model-based engineering (MBE) methods are a possible way to address this topic.

In model-driven engineering (MDE), models are used as the primary artifacts during the software engineering process [4]. Hence, models are used for specification, design, implementation, integration and validation of a system and play the central role in the development. Model-based engineering, on the other hand, often refers to "softer version of MDE" [4]. There are many more terms to describe the use of models in software engineering processes, such as model-driven development (MDD), model-driven software engineering (MDSE), or model-driven architecture (MDA). As those terms are not used consistently in the literature, we use the term model-based engineering (MBE) throughout the paper to describe a systems engineering process based on, or driven by, models.

MBE should bring several advantages such as quality improvements, productivity improvements [3, 13], or increased understandability [10]. But how is the application of MBE in practice? Does automatic code generation work well? Does the abstraction of functions help to understand the system? Do tools support MBE sufficiently? In order to gain an understanding of how MBE is used in practice, a survey was created by the authors. We obtained 112 answers which we used for data analysis. The survey results should help to get information about advantages and challenges coming along with MBE in practice, to get knowledge about methods and tools applied in embedded domain and to recognize differences in application of MBE across companies and domains for example. The results presented in this technical report are based on the same survey as published in [12], but presents a more detailed view on the data.

1.1 Purpose

The main purpose of the created survey is to get an overview about the State of Practice (SoP) as well as the needs from industry regarding model-based engineering and model-based system analysis methods. More precisely, with the study we want to answer the following questions:

- What is the current state of practice of Model-Based Engineering in the embedded systems domain?

- What are the preceived advantages of disadvantages of Model-Based Engineering?
- How does the use and the assessment of Model-Based Engineering differ between different demographic subgroups in the embedded systems domain?

The first question aims to capture the SoP of MBE in the embedded systems domain, which includes the used modeling environments, modeling languages, types of notations, purposes models are used for and the amount of activities in the development which uses MBE compared to non-MBE. The second question addresses the introduction reasons and the effects, both positive and negative, after introduction of MBE as well as current shortcomings of this method. With the third question, we want to find out whether there are substantial differences in the SoP between different groups in the embedded systems domain, e.g., differences between the automotive domain and the avionics domain or between OEMs and suppliers. In this report, the raw results of the survey are described. Therefore, all questions of the survey and their answers are shown in an uninterpreted form.

1.2 Survey Scope

The study was designed by three researchers from two different institutions and three practitioners from two different companies as part of the CRYSTAL (Critical System engineering Acceleration) project [1]. The final outcome of the study design was a questionnaire consisting of 24 closed-ended and open-ended questions. The first part of the questionnaire contained 13 questions gathering demographic data and the second part, with the 11 remaining questions, aimed at gathering the SoP. It targeted on software architects, developers, project managers, system engineers, etc. from OEMs and suppliers from the embedded systems domain. For creation and distribution of the survey an online survey tool has been chosen. The hyperlink has been distributed to all Crystal partners, to partners from further EU projects, as well as to personal contacts of which most are professionals working with MBE. The 121 completed surveys were made anonymous by the survey tool, 9 of them were filtered and the results of the 112 remaining answers are presented in this report.

1.3 Overview

The remainder of this paper is structured as follows. In section 2 related surveys and papers are referenced. Section 3 provides information about the process of survey creation, data collection and threats of validity. Section 4 shows the raw results of the survey. This includes the demographic data of the participants as well as SoP results. The last section summarizes the results of the survey and provides some prospects regarding MBE research.

[1] http://www.crystal-artemis.eu/

2 Related Work

While industrial evaluation of MBE in research is limited [10], there are a number of recent publications addressing this topic. With respect to the embedded systems domain, we are only aware of two reported studies, [1] and [11], presenting the SoP of MBE in this particular domain. Additionally, the current status with respect to MBE tools is presented in [8]. Other publications, such as [3, 13] and [9], also include cases from the embedded systems domain, but do not explicitly address this domain as their target.

2.1 Empirical studies on MBE in the Embedded Industry

In [1], Agner et al. present the results of a survey on the use of UML and model-driven approaches in the Brazilian embedded software development industry. The participants come from a variety of different sub-domains, with industrial automation, information technology, telecommunications and electronic industry being the biggest groups. Key findings are that 45% of the 209 participants use UML. Of these 45%, the majority are experienced developers working at medium-sized companies. The subjects report increases in productivity and improvements in quality, maintenance and portability as key advantages of model-driven practices. According to the participants, the use of UML is mostly hindered by short lead times, lack of knowledge regarding UML and a limited number of employees with expert UML knowledge. Additionally, it is stated that models are mainly used for documentation with only little use of code generation or model-centric approaches in general. In contrast to [1], we do not limit ourselves to a region but include a wide range of subjects from global companies based in Europe.

Kirstan and Zimmermann report a case study within the automotive domain [11]. Their interviewees report positive effects of MBE like an earlier detection of errors, a higher degree of automation and cost savings during the initial phases of development. On the negative side, they state that large function models can become too complex and that interoperability between tools is difficult. The study is limited to qualitative data from a single sub-domain of the embedded systems domain, namely automotive.

Herrmannsdoerfer and Merenda report a survey of 24 practitioners within the embedded domain on the status of tools within MBE [8]. Their findings are that tools for MBE are not yet “fully appropriate” for efficient model-based development and that the most pressing need is the integration of different tools.

2.2 Empirical Studies on MBE in general

Baker et al. present experiences with MBE at Motorola over a time span of almost 20 years in [3]. On the positive side, they report a defect reduction and an improvement in productivity. However, a number of challenges regarding MBE are named as well, such as lack of common tools, poor tool and generated code performance, lack of integrated tools, and lack of scalability.

Mohagheghi and Dehlen published a literature review on the industrial application of MBE [13]. The evidence collected during the review suggests that the use of MBE can lead to improvements in software quality and productivity. However, studies which report productivity losses are also quoted in the review. Insufficient tool chains, modeling complexity, and the use of MBE with legacy systems are reported as challenges. Additionally, the maturity of tool environments is stated to be unsatisfactory for a large-scale adoption of MBE. Generally, the authors conclude that there is too little evidence in order to generalize their results.

In a later publication by Mohagheghi et al., experiences from three companies in a European project "with the objective of developing techniques and tools for applying MDE" are reported [14]. According to the experiences at the studied companies, advantages of using MBE include the possibility to provide abstractions of complex systems, simulation and testing, and performance-related decision support. However, the authors also state that the development of reusable solutions using MBE requires additional effort and might decrease performance. Moreover, transformations required for tool integration can increase the complexity and the implementation effort according to the authors. Furthermore, the user-friendliness of MBE tools and means for managing models of complex systems is described as challenging.

Hutchinson et al. report industrial experiences from the adoption of MBE at a printer company, a car company and a telecommunications company in [9]. The authors conclude that a successful adoption of MBE seems to require, among others, an iterative and progressive approach, organizational commitment, and motivated users. The study is focused mainly on organizational challenges of MBE.

A further assessment of MBE in industry by Hutchinson et al. based on over 250 survey responses, 22 interviews, and observational studies from multiple domains is presented in [10]. From their survey, the authors report that significant additional training is needed for the use of MBE, but that MBE in turn can speed up the implementation of new requirements. Furthermore, the survey indicates that code generation is an important aspect of MBE productivity gains, but integrating the code into existing projects can be problematic. The majority of survey participants states that MBE increases understandability. From their interviews, the authors conclude that people's ability to think abstractly can have a huge impact on their ability to model. Hence, this ability influences the success of MBE.

According to a survey of 113 software practitioners reported by Forward and Lethbridge, common problems with model-centric development approaches are, among others, inconsistency of models over time, model interchange between tools and heavyweight modeling tools [6]. Code-centric development approaches, on the other hand, make it difficult to see the overall design and hard to understand the system behavior.

Torchiano et al. present findings from a survey on the State of Practice in model-driven approaches in the Italian software industry [20]. From the 155 subjects, 68% report to always or sometimes use models. The subjects who do not use models commonly state that modeling requires too much effort (50%) or is not useful enough (46%). Further findings are that models are used mainly in larger companies and that a majority of all the subjects using models (76%) apply UML.

2.3 Other Studies

Further empirical evaluations on the application of UML in particular can be found in [7, 2, 5]. These publications are related to our survey with respect to some aspects, such as UML notation types. However, they do not address MBE, or any approach where models are the primary artifact, in particular. Therefore, they are not discussed here in detail.

2.4 Summary

In conclusion, commonly reported problems in industry are insufficient tool support or tool chains, using MBE together with legacy systems, and the complexity of MBE and modeling in general. On the positive side, productivity gains, defect reductions and increased understandability are reported. However, there is a lack of empirical evidence and reported industry evaluations on the use of MBE within the embedded systems domain. Existing work is either not targeted at the embedded systems domain in particular [3, 13, 14, 9, 10, 20], is limited to the Brazilian market [1], is limited to tooling aspects [8], or lacks quantitative data [11].

3 Research Methodology

This section is concerned with the research methodology, consisting of design, execution, and validation of the performed survey. The complete survey data has been published together with a further analysis in [12] and is available on `www.cse.chalmers.se/~tichy/models14_LMTLH_dataset.zip`[2].

3.1 Goals of study

Research questions

The main goal of the study, presented in this report, is to obtain an overview about the State of Practice of Model-Based Engineering in industry. In order to obtain usable answers, the goals of the study have to be designed as specific as possible [21]. Hence, several research questions (RQ1 to RQ6), which should be answered with the study, have been formulated.

- State of practice in industry
  - **RQ1:** Which modeling techniques, modeling languages, and modeling tools are used in industrial practice?
  - **RQ2:** In which phases of the software development process is model-based engineering used?
  - **RQ3:** How much time of the overall software development work is spent on model-based engineering?
  - **RQ4:** Which methods exploiting models are used for validation and verification?
- Advantages and disadvantages of Model-Based Engineering in industry
  - **RQ5:** Which positive and negative effects result from the adoption of Model-Based Engineering?
- Differences in Model-Based Engineering
  - **RQ6:** What are the differences on the use and assessment of Model-Based Engineering in different sub-classes of companies and users?

[2]Password: mbe_usage14

Study strategies

In Table 3.1, criteria are given for different study strategies [16]. There are three strategies: Experiment, Case Study and Survey. With an experiment, causal relationships are analyzed in order to confirm or refute theories. The control on who is using which technology, when, where and under which conditions is possible. This method is appropriate for investigating self-standing tasks from which results can be obtained immediately. Case studies on the other hand investigate a typical case in realistic representative conditions. The change to be assessed is wide-ranging throughout the development process and the assessment in a typical situation is required. In contrast to experiments and case studies, surveys only collect and investigate information; hence, there is a low possibility of control. The information source for surveys are people, projects, organizations or also the literature. Surveys are suitable in cases where a technology change is implemented across a large number of projects and the description of results, influence factors, differences and commonalities are needed.

	Purpose	**Required Control**
Experiment	Establish causal relationships, confirm theories	high
Case Study	Investigate a typical “case” in realistic representative conditions	medium
Survey	Investigate information collected from a group of people or projects or organizations or literature.	low

Table 3.1: Criteria for research method selection [16]

As far as our experiences go, MBE is already widely implemented especially in the automotive sector and the distribution has progressed similarly in other industrial branches. Therefore, surveys are a well fitted strategy as they are suitable for collecting empirical data from large populations. Figure 3.1 shows the different strategies over the life cycle of a new technology. It is taken from [16] which is mainly adapted from [22] showing Gorscheks technology transfer model. It can be seen that the most appropriate strategy is changing depending on the progress of development. As explained above, we think that MBE is already a widespread technology in some domains, meaning that introduction progress has reached the end of the series shown in Figure 3.1. Hence, carrying out a survey is appropriate for our study.

3.2 Survey design

Design survey process

In [18], a survey is described as “a research process in which new information is collected from a sample drawn from a population, with the purpose of making

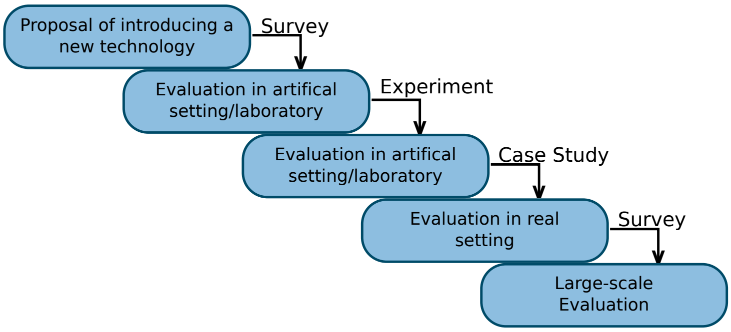

Figure 3.1: Empirical strategies evaluating a new technology [16]

inferences about the population". Surveys can be a powerful instrument for collecting empirical data from large groups of people, but only if well thought through. The biggest drawback in carrying out a survey is the demand of resources that is needed in order to obtain an adequate response rate. In many cases a survey will contain a questionnaire for the purpose of data acquisition. Nevertheless, a survey should not be reduced to this questionnaire and the corresponding responses, but it should be seen as a "fully integrated part of the research strategy [18]". According to [15], a survey can be considered as a process comprising several steps (depicted in Figure 3.2). The survey presented in this report was also conducted following this process.

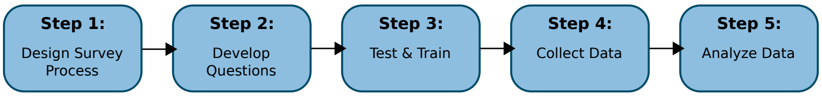

Figure 3.2: Survey process according to [15]

Develop Questions

The questions for the survey have to be extracted from the goals of a study [19]. In our case the goals of the study represent the research questions (cp. Section 3.1). Based on these questions we developed a questionnaire which consists of two main parts:

1. Context: In this part information is gathered about company's context as well as personal experiences of the participants. With the company related questions we wanted to get an idea of the work environment such as domain, company size or company position. Questions about the personal experiences such as daily working tasks, usage of MBE or whether a participant is a supporter for MBE or not should help to better understand answers and opinions of the surveyed subjects.

2. Model-Based Engineering: The second part of the questionnaire contains questions about used modeling languages, methods and tools as well as advantages and challenges regarding MBE. With these questions we wanted to get information about the State of Practice.

Nearly all questions were single-choice (radio buttons) or multiple-choice (checkboxes) which is best suited for automatic statistical analysis. Where applicable, free-text areas for additional input were provided. In order to prevent misunderstandings, which could lead to invalidity of conclusions, great importance was attached to survey questions, formulations and explanations.

Further, we attached great importance to the usability of the questionnaire in order to get a high response rate. We reduced the number of questions, gave a detailed introduction and explained the questions for this purpose.

Test & Train

To test a survey before distributing it is a very important step to be passed through. The survey was piloted by eleven colleagues in academia and industry. Given their feedback and the time they needed to fill out the survey, the questionnaire was refined. The revised survey was reviewed a second time by one colleague not included in the pilot survey. Since no interviewers were involved for executing the survey, no training was necessary. Finally, the survey questionnaire consisted of 24 closed-ended and open-ended questions. The complete questionnaire is depicted in Appendix A.

Collect data

Target Population

In the current survey, the identified targeting population are people working in an industrial or academic environment, engaged in Embedded Systems Development. We distributed the survey to partners taking part at the Artemis projects Crystal (70 partners), VeTeSS (22 partners), MBAT (38 partners), nSafeCer (29 partners), and EMC^2(100 partners), as well as to personal contacts of which most are professionals working with MBE. However, we also encouraged recipients to distribute the survey to colleagues or partners.

Survey distribution and data collection

We used an online survey[1] in order to keep administration costs low and "facilitate the whole survey process vastly [17]". Potential participants were invited for the survey by email in which full anonymity was guaranteed in order to avoid non-attendance. The final version of the survey was published on 18th October 2013 for a time period of six weeks. During that time the number of answers has been checked periodically and intermediate results have been downloaded in order to discover possible errors or problems at an early stage. At the end, 196 people started to fill out the survey, 121 surveys were completed corresponding to a completion rate of 61.73%.

Analyze Data

The last step of the survey process is to analyze the collected data. The survey data was automatically coded and enhanced with additional quality data by the survey tool, such as completed answers and time to fill out the survey. In

[1] through www.soscisurvey.de

order to handle challenges such as incomplete surveys and missing data, we cleaned the remaining 121 surveys based on degradation points computed from missing answers and the time to fill out at each survey page. As we did not use compulsory questions, it could happen that subjects lost interest but still navigated through the entire survey until the end or simply looked at the survey without filling in data. Therefore, we argue that this data cleaning process is necessary in order to ensure data validity as discussed in [22]. We excluded nine surveys based on a threshold of 200 degradation points proposed by the survey tool for a light data filtering. This left us with 112 answered surveys for data analysis. Further, we made adaptations to the demographic data in cases where free-text answers clearly corresponded to one of the given answering options. Detailed results of the survey are discussed in the next chapter.

Validity Threats

In the following, we discuss the four different aspects of validity as discussed in Wohlin et al. [22].

Construct Validity

Construct validity reflects whether the studied measures are generalizeable to the concept underlying the study. We collected data from different sources in order to avoid mono-operation bias. Hypothesis guessing, the participants guessing what the researchers are aiming for and answering accordingly, can not be ruled out completely. We tried, however, to formulate the questions in a neutral way and improved the questionnaire based on obtained feedback from the pilot study in order to address this threat. Finally, answers were treated completely anonymous in order to avoid biased answers due to evaluation apprehension.

Internal Validity

Internal validity reflects whether all causal relations are studied or if unknown factors affect the results. Instrumentation was improved by using a pilot study. The survey took approximately 15 minutes to fill out and was intended to be filled out once by every participant. This reduces the likelihood for learning effects and, hence, maturation effects. Additionally, the completion rate of 61.73% indicates that the majority of participants was interested in finishing the survey. Selection threats can not be ruled out as participants volunteered to fill out the survey.

External Validity

External validity is concerned with the generalizeability of the findings. The CRYSTAL project and other projects, to which the survey was distributed, consist of partners from all major sub-domains of the embedded systems domain. Additionally, demographic data was collected in order to confirm this aspect. Therefore, we are confident that we have reached subjects with a variety of different backgrounds representative for the embedded systems domain. While CRYSTAL is a project on European level, many of the involved partners are global companies. Hence, we argue that this does not limit the validity of our results and that it is possibile to generalize them to other cases on non-EU level.

Conclusion Validity

Conclusion validity is concerned with the ability to draw correct conclusions from the studied measures. We involved three researchers and three practitioners with different background into the study design. Therefore, the survey was designed by multiple people with different aims and backgrounds, which should reduce the risk for "fishing" for results. A standard introduction e-mail was designed to be distributed with the link to the online survey. Hence, reliability of treatment implementation is given. Reliability of measures was increased through a survey pilot filled out by eleven people and then, after improvements, reviewed by one more researcher. The detailed questionnaire is furthermore published in order to enable replications and an assessment of the validity of our study.

4 Survey Results

4.1 Demographic Data

The first part of the survey contained context questions providing demographic data. This includes first, some context questions concerning the company and secondly, questions about the personal MBE experiences of the participants. With the company related questions we wanted to get an idea of the work environment such as domain, company size or company position. Questions about the personal experiences such as daily working tasks, usage of MBE or whether the participant is a supporter for MBE or not should help to better understand answers of the surveyed subjects.

The following figures, Figure 4.1 - Figure 4.12, show the results for the context questions. One question, which was optional to fill in, asked participants for the company they work for. More than half of the participants stated the company they worked for and at least 30 different companies could have been identified that participated in the online survey. About three-fourths of all respondents (87) work in large companies with more than 250 employees, 14 persons are employed in small and medium enterprises (SME) and 11 at university (Figure 4.1). Hence, the main percentage of answers represent opinions of large companies. More than a half of the respondents (60) work in the automotive industry, 31 in avionics, 25 in health care, 15 in defense, 11 in rail and 4 in telecommunications (Figure 4.2). 16 companies work domain independently and 9 operate in other domains such as semiconductor or industrial automation industry.

50 of the companies are first-tier supplier, 40 OEMs, 25 second-tier supplier and 18 have other positions in the value chain such as research institutes, consultants or technology/software provider (Figure 4.3). Asking the surveyed subjects about a typical work group size in their company, 28 survey participants say that the group has a size of 0-5 persons, 42 say 5-15 persons and 41 participants work in groups with more than 15 persons (Figure 4.4).

In order to understand for which activities the participants use MBE, we asked for their main working tasks. The answers, multiple answers were possible, are: 60 of the participants implement software, 56 are responsible for architecture definition, 55 for testing, 53 for design definition, 49 specify requirements, 39 are project managers, 24 are safety managers, 16 are quality managers, 14 are responsible for customer support and 12 work in general management (Figure 4.5).

The used standards are shown in Figure 4.6. Most used standard is the ISO26262 what could have to do with the fact, that more than the half of the participants work in the automotive industry. Further frequently used standards

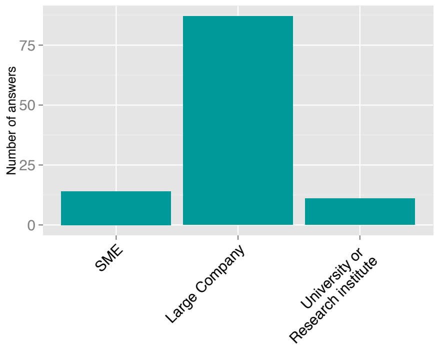

Figure 4.1: Company size

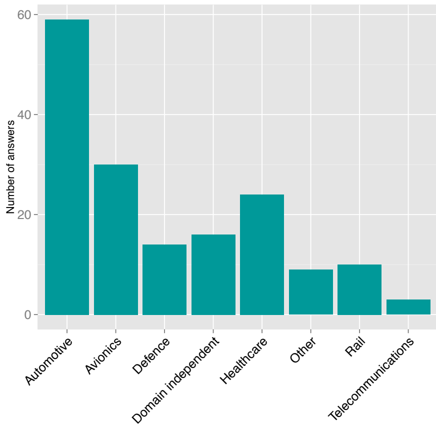

Figure 4.2: Domain

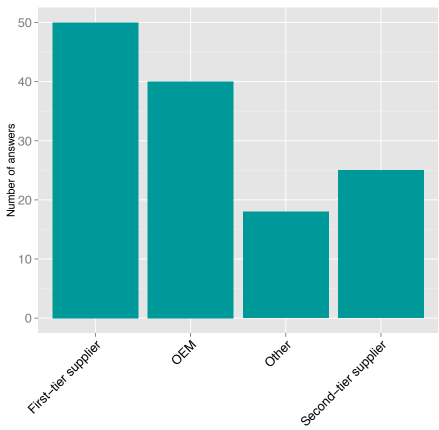

Figure 4.3: Company's position

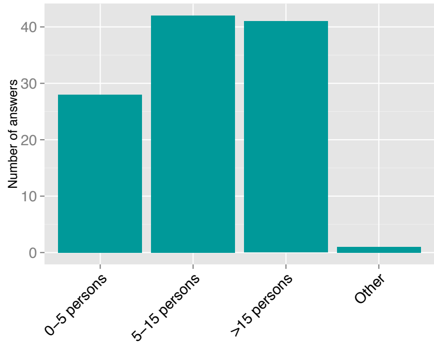

Figure 4.4: Work group size

are ECSS-E-40, ECSS-Q-80, ARP4754, ARP4761, ISO14971 and ISO13485.

Since the understanding for the term Model-based Engineering is diverse in interpretation, we asked the surveyed subject what they think what MBE is. MBE allows for fast formal and simulative validation (68) was the most common answer. 55 think MBE is a method to reduce probability of systematic error and 51 think that it is a technique to speed up the design process. Statements that meet with little response are MBE makes use of problem-oriented structures (22) and MBE is a new software and systems development paradigm (25). Free text answers, which are summarized with 'other' in Figure 4.7, are statements like 'enables functional integration', 'is a wishful thinking', 'is still an immature technology', 'is a term which is not clearly and precisely defined' or 'is a way to cope with increasing system complexity'.

Concerning the MBE experience, many participants (46) are well experienced with more than 3 years of usage. 40 persons state that they have moderate

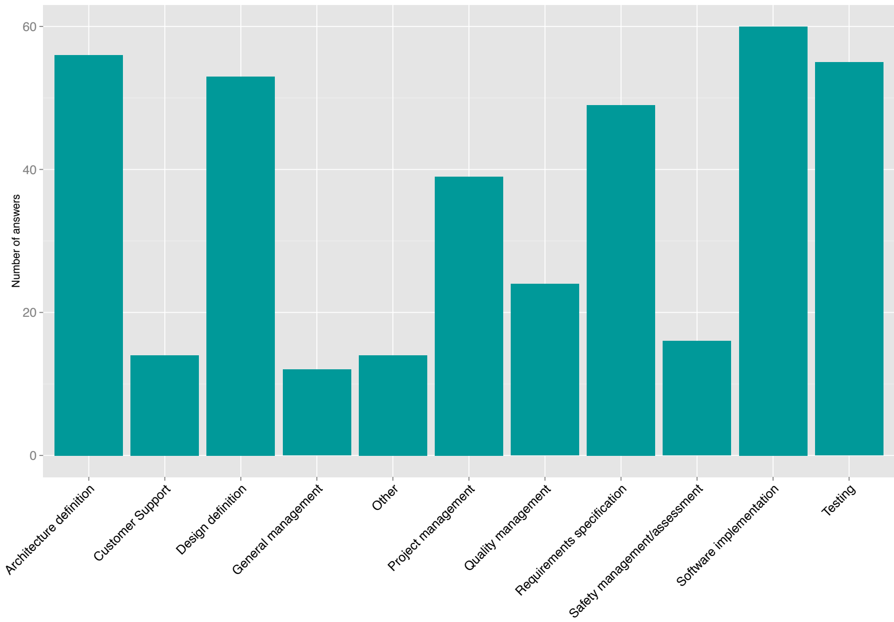

Figure 4.5: Working tasks

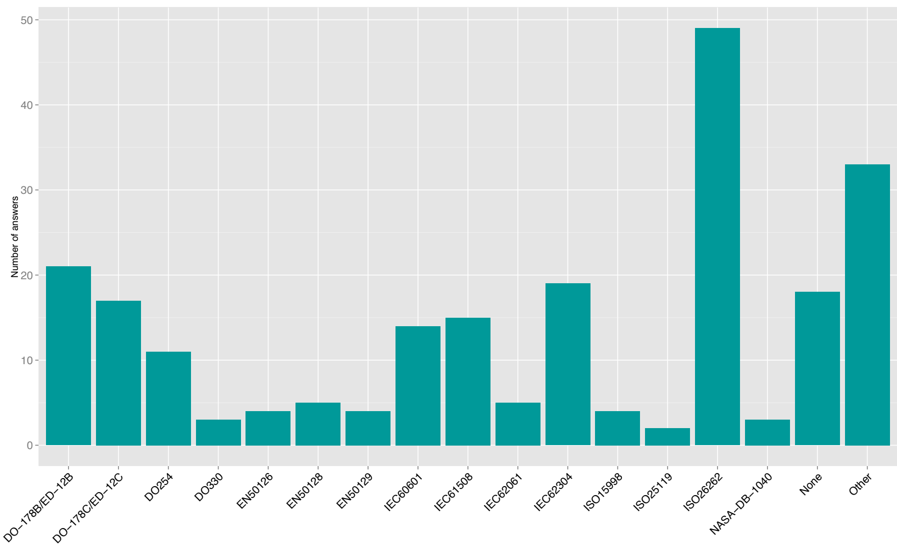

Figure 4.6: Used standards

experience and only 26 are new in the field of MBE (Figure 4.8). Asking the participants the point in time their company introduced MBE, 37 say that their company started 10 or more years ago, 56 state 1-10 years ago and 4 started in the last 12 months (Figure 4.9).

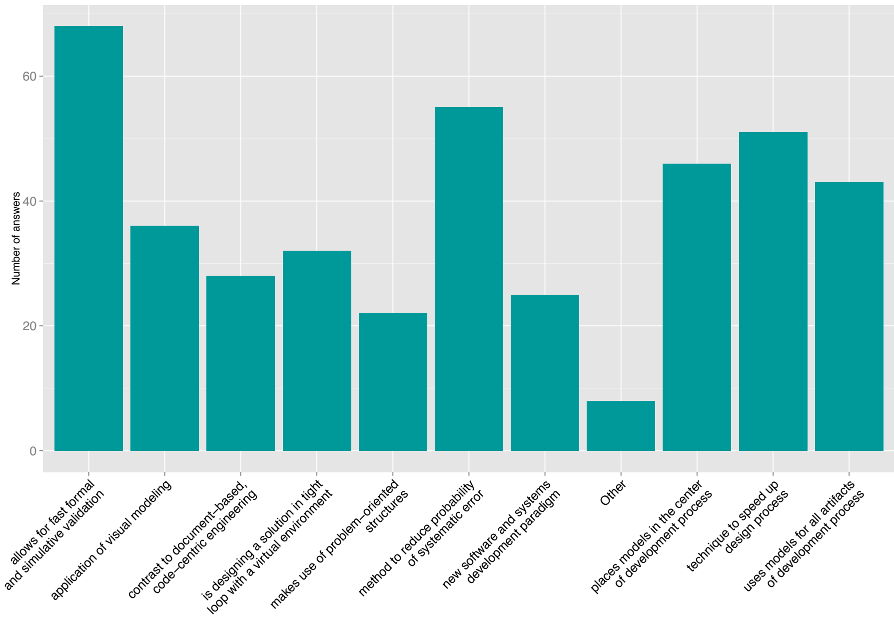

Figure 4.7: MBE definition

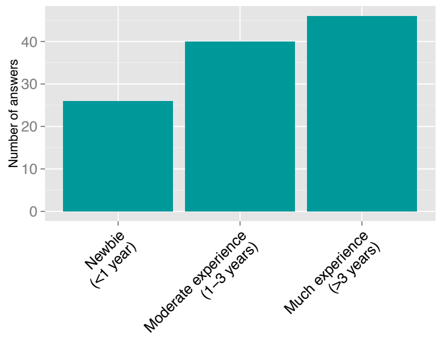

Figure 4.8: MBE experience

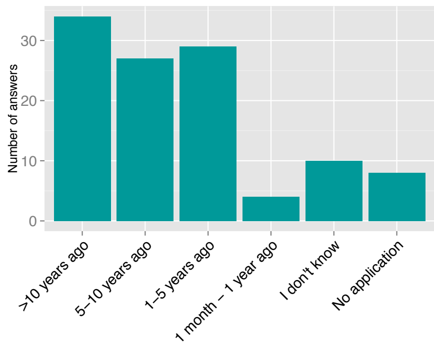

Figure 4.9: Start of MBE usage

72 of the participants are still using MBE, 15 have used MBE the last time 1 month to 1 year ago and 16 have used MBE the last time more than 1 year ago. Only 9 people state that they have never used MBE; thus, a large percentage of the survey participants are experienced (Figure 4.10). 86 of subjects are promoters for MBE, 25 have a neutral attitude for MBE and 0 are opponents (Figure 4.11).

73 companies use MBE for developing a commercial product, 46 therefrom for large scale series production (more than 1000 pieces), 19 for medium scale production and 8 for small scale production (less than 10 pieces). 23 use MBE for research demonstration, 9 for non-commercial products and 7 for other

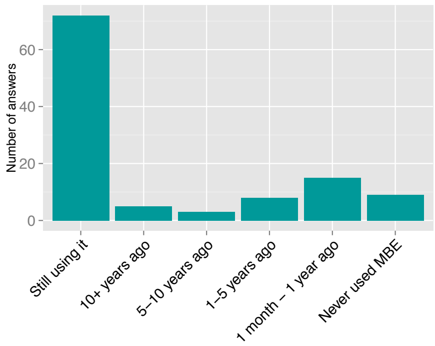

Figure 4.10: Personal last use of MBE

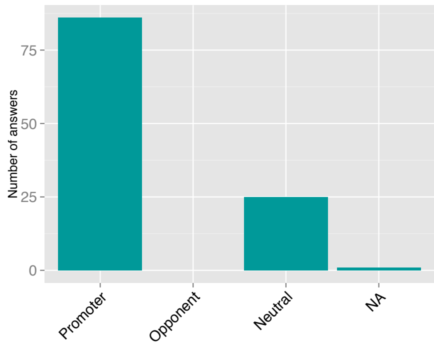

Figure 4.11: Attitude

purposes such as teaching or developing methods and tools (Figure 4.12).

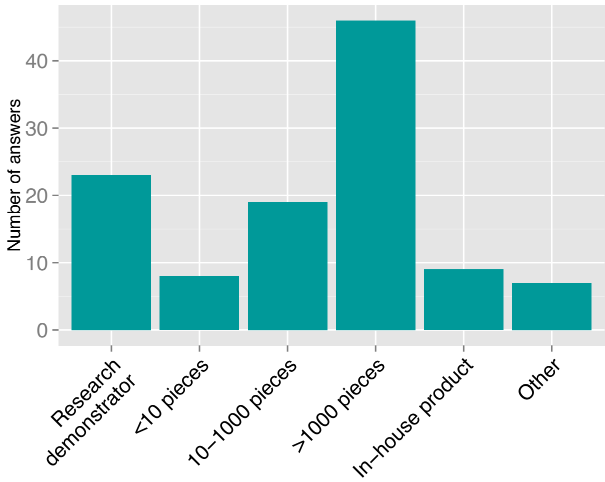

Figure 4.12: Target product

4.2 RQ1: Which modeling techniques, modeling languages and modeling tools are used in industrial practice and why?

RQ1 is answered through questions 16, 17, 18 and 23 in the questionnaire (see A). Figure 4.13 shows the answers to question 16. As the plot shows, the majority of survey participants use Matlab/Simulink/Stateflow personally and state that Matlab/Simulink/Stateflow is used within their division or department. Matlab/Simulink/Stateflow is followed by Eclipse-based tools both for personal and division/department use. On division/department level, Eclipse-based tools are closely followed by Enterprise Architect. On personal level there is a larger

gap after Eclipse-based tools. Interestingly, many survey participants stated that Labview is used on division/department level but only very few stated that they use Labview personally. Additionally, some participants provided answers in the other field. Here, IBM Rational Software Modeller, Microsoft PowerPoint, SPIN model checker and Borland Together were mentioned among other, less known, tools.
The use of different modeling languages is depicted in Figure 4.14. The majority of survey participants uses UML, on division/department level followed by SysML. For personal use, the amount of answers for SysML and no modeling language are similar. In the other fields, EAST-ADL and AUTOSAR were commonly mentioned. Especially the amount of personal "None" answers is surprising, as there are only few participants who answered "None" for personal use in question 16 and 18. This might indicate that question 17 might have been misunderstood or unclear to some participants.

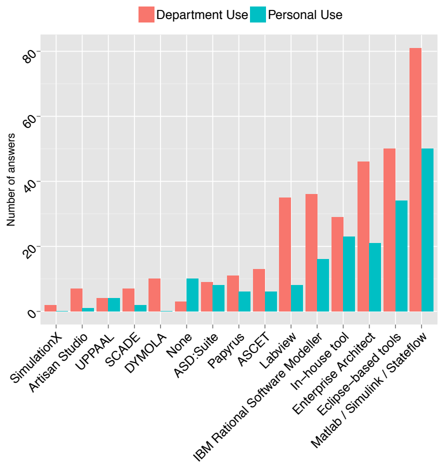

Figure 4.13: Modeling environments

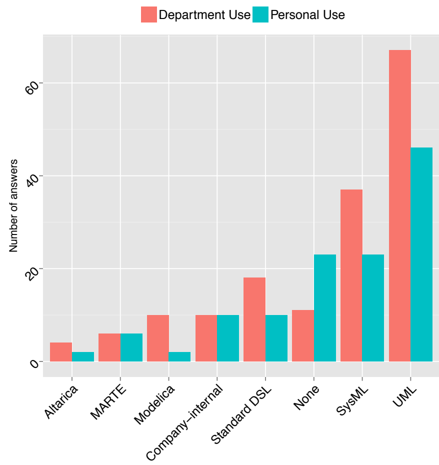

Figure 4.14: Modeling languages

The different types of notations used by the survey participants on personal and division/department level are depicted in Figure 4.15. Clearly, finite state machines, sequence-based models, structural models and block diagrams are the most used notation types for both personal and division/department use. The remaining notation types have substantially fewer answers with only five participants not using any type of notation.

Different types of integration mechanisms are used by the subjects. These are depicted in Figure 4.16 which represent answers for survey question 23. Most common data exchange is import and export via defined file formats and tool adapters. Usage of common databases for multiple tools, message passing, (hyper-)links, and no automatic integration are less common.

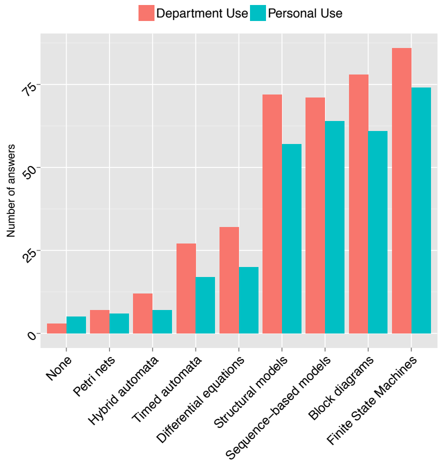

Figure 4.15: Type(s) of notations

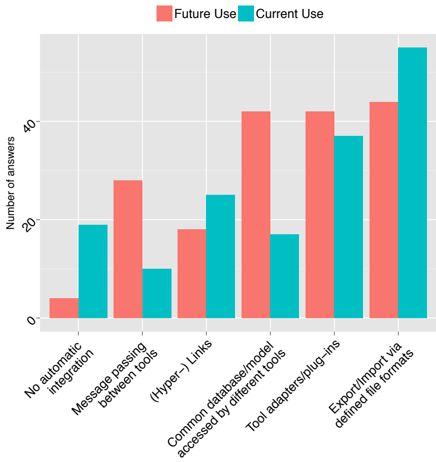

Figure 4.16: Type(s) of integration mechanism(s)

4.3 RQ2: In which phases of the software development process is model-based engineering used?

Research question 2 can be answered with survey question 24: 'In which phases of the development process are you using model-based engineering?'. The answers show that models are used in the overall development process (Figure 4.17). Mainly, they are used for architecture, design and implementation. System test and integration test are the phases where models are fewest applied according to the participant answers.

4.4 RQ3: How much time of the overall system and software development work is spent on model-based engineering?

The third research question can be answered with question 20 of the survey, namely 'How would you compare your usage and the usage within your division/department of model-based and non model-based tools for performing engineering activities?'. The answers for this questions show that most participating companies use both MBE tools and non MBE tools. However, the amount of answers 'use more MBE tools than non MBE tools' dominate the answers. Only a small percentage state that they use only MBE tools or no MBE tools. Figure 4.18 presents an overview of the given answers for both personal use and company wide use.

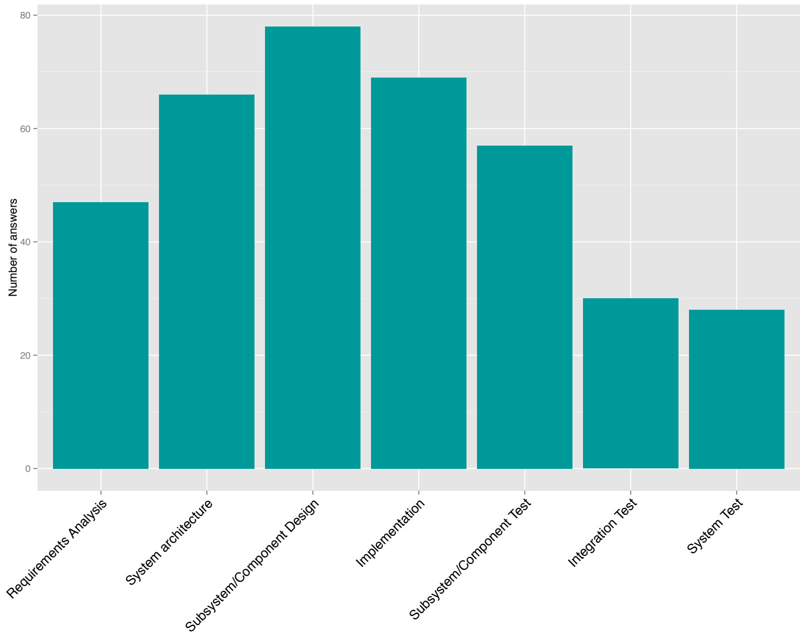

Figure 4.17: MBE used in various development phases

4.5 RQ4: Which methods exploiting models are used for validation and verification?

RQ4 is addressed by survey questions 18, 19, and 22. The outcomes of survey question 18 are already discussed in section 4.2. Regarding survey question 19, a majority of all subjects use models for structure aspects both on personal level and department level. This aspect is closely followed by discrete state/event based specifications and static interfaces. From there on, the usage is declining approximately linearly with approximately 20 people using models for safety aspects and hybrid behavior on personal level. The results for this question are depicted in Figure 4.19.

Over 70 subjects reportedly use models for simulation and code generation (survey question 22). Over 40 participants also use models for information or documentation, test-case generation and structural consistency checks. Less than 20 subjects use models for reliability analysis and only 5 subjects do not use models. Additionally, it was mentioned that models are used for measurement verification by one participant. The results for this question are depicted in Figure 4.20.

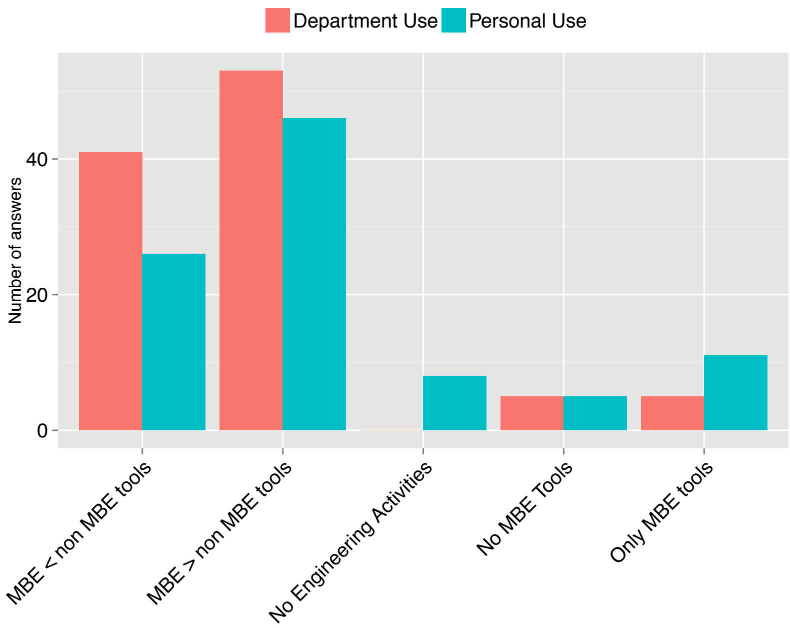

Figure 4.18: MBE and non-MBE usage in development

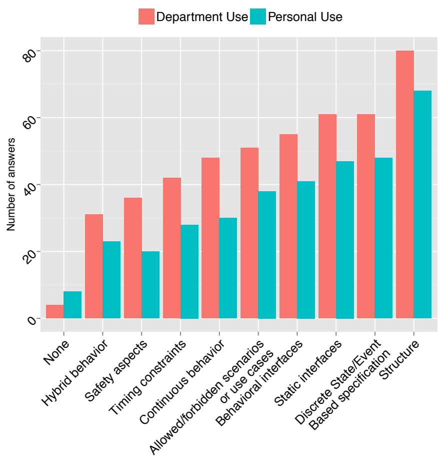

Figure 4.19: Types of notations

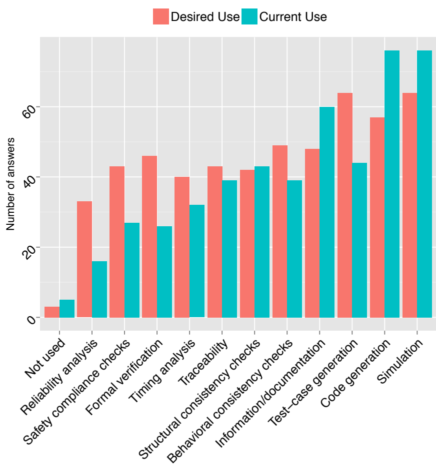

Figure 4.20: Functional Aspects

4.6 RQ5: Which positive and negative effects result from the adoption of model-based engineering?

For answering this research question, we formulated three questions in the questionnaire (question 14, 15 and 21). We asked the participants about the reasons for MBE introduction, the effects of MBE, both positive and negative, as well as the shortcomings.

Needs for introducing MBE

An interesting issue is the motivation why companies decide to use models for developing their systems. Reasons for introducing MBE will give information about companies' opinions regarding the advantages of MBE as well as challenges they are faced with. The results for question 14, which asks about the needs for introducing MBE, are summarized in Figure 4.21.

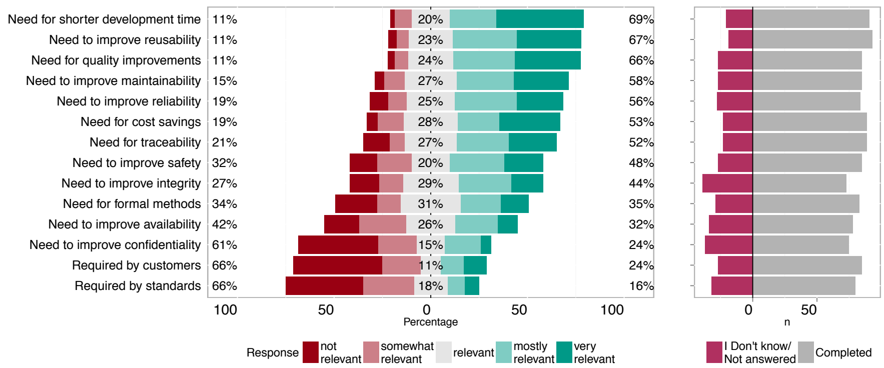

Figure 4.21: Reasons for introducing MBE

On the left side of the figure, the needs, which have been stated in the questionnaire, and the responses concerning the needs are listed. The three percentage declarations in the figure show on the left side the percentage of the answers with 'not relevant' and 'somewhat relevant', in the middle the percentage of the neutral 'relevant' answers and on the right side the percentage of answers with 'mostly relevant' and 'very relevant'. The second part of the figure, located on the right side, gives information about the amount of participants who filled in the grade (completed) and the number of participants who did not fill in a grade or did not know it (Not answered/I don't know). The figures in the following sections can be read equally, but with adapted questions, responses and response types. As the figure shows, most participants (69%) think that their company adopted MBE because they had a need for shorter development time. Further, more than 50% say that needs for reusability, quality, maintainability and reliability improvements as well as cost savings and traceability are reasons for applying MBE. More insignificant needs are that MBE is required by customers or standards.

Positive and negative effects of MBE

In addition to the needs for introducing MBE, the effects of the actual use of MBE are interesting, too. There are positive and negative effects when applying MBE; hence, we asked in question 15 'What were the effects of introducing MBE in your division/department?'. Figure 4.22 shows the answers for this question.

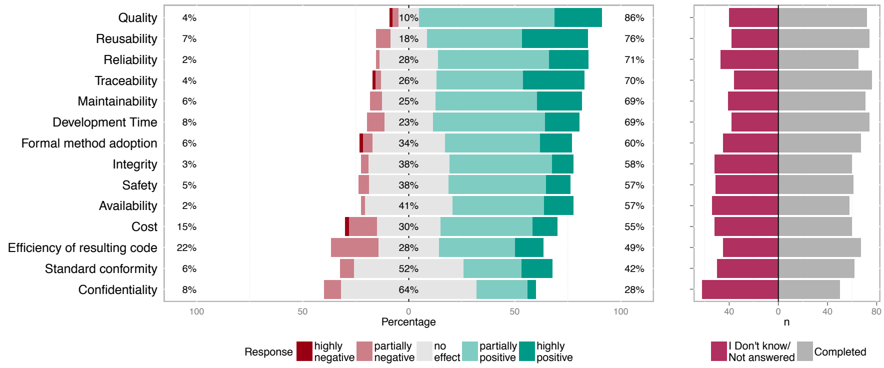

Figure 4.22: Positive and negative effects of MBE

Accordingly, quality, reusability, reliability, traceability, maintainability and development time are the most positive effects of MBE. Standard conformity and confidentiality have no effect according to more than 50% of the surveyed subjects. Thus, most survey participants think that MBE has more positive than negative effects.

Shortcomings of MBE

In order to identify potential improvements, subjects were asked about current shortcomings of MBE. Figure 4.23 shows the answers for this question which range from does not apply at all to fully applies.

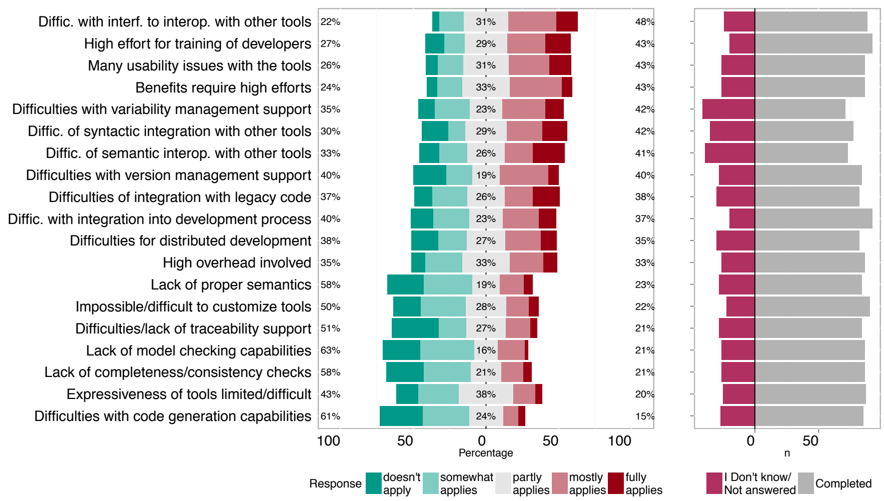

Figure 4.23: Shortcomings of MBE

Many survey participants think that difficulties with interfaces to interoperate with other tools is a shortcoming that fully or mostly applies. This is in line with survey results in [6]. Moreover, more than one third of the people thinks that MBE requires a high effort to train developers, that there are usability issues with tools and that benefits require high efforts. Negligible shortcomings according to the responses are difficulties to customize tools and limitations on what can be expressed within tools. Hence, although the interoperability between tools seems to be a main shortcoming, capabilities of single methods and tools are satisfactory for many surveyed subjects.

4.7 RQ6: Differences in subclasses of users

In the following, we will discuss the differences between subclasses of survey participants with respect to the previous research questions. We address the different subdomains, the different positions in the value chain, the company size and the product size targeted by the participants' employers. The demographics of these subgroups have already been discussed in Section 4.1 and will only be shortly summarized for clarity in each subsection.

Domain

Out of the 112 subjects, 59 were from the automotive domain, 30 from avionics, 24 from healthcare, 10 from railway, 16 domain independent, 14 from defense and 3 from the telecommunications domain. Telecommunications is left out in the following discussion, as only three subjects placed themselves in this domain.

RQ1 and RQ4 do not show any noticeable differences between the different domains.

With respect to RQ3, MBE tools are more common than non-MBE tools in the automotive, railway and defense domains. In avionics the tool use is balanced between MBE and non-MBE tools, both for personal use and on department level. For subjects working domain independently, there is less use of MBE tools than non-MBE tools.

Regarding RQ5, there are three different aspects to consider: the needs for introducing MBE, the effects of introducing MBE and the shortcomings of MBE named by the subjects in different domains. In Table 4.1, the three answers which received the highest ratings by the participants for each of the three aspects are summarized. The depicted percentages refer to the percentage of participants that answered 'Very relevant' or 'mostly relevant' for the introduction needs, 'Highly positive' or 'partially positive' for the effects of introducing MBE, and 'Fully applies' or 'mostly applies' for the shortcomings of MBE. However, as answers sometimes have the same percentage, such as reusability (81%) and quality (81%) as positive effects in the automotive domain, we further prioritized answers having more highest gradings to answers with less highest gradings in the ranking. More precisely, if reusability would have 50% 'highly positive' answers and quality only 30% 'highly positive', reusability would be on second position and quality on third position, although the percentage is the same (81%). In cases where we do not have enough answers, the table cell contains 'na' (not available) such as in the rail domain. Anyway, the needs for introducing MBE are comparable to the overall outcome for this question. Shorter development time, improved reusability and improved quality were named as needs by subjects in the automotive, avionic, healthcare and defense domain and by domain independent subjects. The order in which these are named varies however between the domains. Subjects within automotive, for example, name the need for shorter development times first (with 75% stating it as mostly or strongly relevant), whereas in avionics the need for reusability is named first (83% mostly or strongly relevant). Similarly, the needs which were opted to be least relevant were the need to improve confidentiality, required by standards and required by customers.

The actual effects of introducing MBE differ between domains. Within automotive, most subjects agreed on positive effects on development time (86% positive), reusability (81% positive), quality (81% positive) and traceability (80% positive). In avionics, positive effects on quality were reported by 90% of the subjects, followed by formal method adoption (74%) and reusability (72%). Subjects within the healthcare domain also reported very positive effects on quality (88% positive), however followed by maintainability and traceability with each 67% positive. Domain independent subjects also reported maintainability (82% positive), quality (80%), reusability (80%) and traceability (80%). In the railway and defense domain, too few answers were obtained to give a representative overview. On the lower end of the scale, confidentiality, cost, and standard conformity are named. However, the actual answers are very different between the domains. While the effects on confidentiality were rated least positive by both the automotive and avionics domain, 42% in the automotive domain still reported these effects to be positive, compared to only 17% in avionics. Additionally, few subjects reported any negative effects in general. Hence, most answers are either neutral or slightly/mostly positive.

The named shortcomings within the different domains are again close to the overall picture. Difficulties with interfaces to interoperate with other tools is reported as the main shortcoming by subjects within the automotive and avionics domains. Interestingly, difficulties for distributed development is the number one shortcoming mentioned by subjects in healthcare, with 58% of these subjects reporting that this mostly or fully applies. Overall, only 35% of the subjects agreed with this position. A high agreement can be seen for domain independent subjects. Here, 83% named that 'benefits require high efforts' partly or fully applies, 80% difficulties with semantic interoperability with other tools and 73% syntactic integration with other tools.

In summary, there are no large differences between the domains with respect to the research questions. This could be interpreted as an agreement. However, we did not collect enough data to substantiate this statement.

Position in value chain

From all 112 survey participants, 41 are from OEMs, 50 are from first-level suppliers and 25 from second-level suppliers. Similarly to the domain subgroups, there are not noticeable differences between these groups with respect to RQ1 through RQ4.

In Table 4.2, the three answers which received the highest ratings by the participants for each of the three aspects are summarized. The percentages follow the same structure as in the previous Section. Again, the needs for introducing MBE for different positions in the value chain are comparable to the overall outcome. The needs which were named mostly are shorter development

		Introduction needs		Positive effects		Shortcomings	
Auto-motive	1.	Shorter development time	74%	Development time	86%	Syntactic integration	85%
	2.	Improve reusability	65%	Reusability / Quality	81%	Interoperability interfaces	71%
	3.	Improve maintainability	62%	Traceability	80%	Variability management	63%
Avionics	1.	Improve reusability	83%	Quality	90%	Interoperability interfaces	54%
		Quality improvements	71%	Formal method adoption	74%	Syntactic integration / Usability	52%
	3.	Shorter development time / improve reliability	65%	Reusability	72%	Version management	48%
Health-care	1.	Improve quality	71%	Quality	88%	Distributed development	58%
	2.	Shorter Development Time	63%	Maintainability / Traceability	67%	Interoperability Interfaces / High training effort	56%
	3.	Improve maintainability	59%	Development time	59%	Development process integration / High efforts	50%
Rail	1.	na		na		na	
	2.	na		na		na	
	3.	na		na		na	
Defense	1.	Improve quality	75%	na		Version management	60%
	2.	Improve reusability	73%	na		Usability issues	55%
	3.	Improve traceability	70%	na		Interoperability interfaces	50%
Domain indepen-dent	1.	na		na		High efforts	83%
	2.	na		na		Semantic interoperability	80%
	3.	na		na		Syntactic integration	73%

Table 4.1: Answers grouped by different domains

time, improved reusability and improved quality. In all three groups, between 72% and 61% subjects reported that these needs were mostly or very relevant.

All three subgroups name a mostly or very positive effect on quality as an outcome of MBE introduction with over 80%. For subjects who work at OEMs, quality is followed by reusability (72% report positive effects) and reliability (68%). At first-level suppliers, positive effects on reliability are reported by 81% of the subjects, while traceability reaches 79%. Finally, second-level suppliers report positive effects in 77% of all cases, and 75% of the subjects mention positive effects on maintainability and traceability.

Similar shortcomings are seen by all three groups as well. Difficulties with interfaces to interoperate with other tools is seen as the main shortcoming by both subjects at OEMs (50% say it partly or fully applies) at second-level suppliers (57%). At first-level suppliers usability and 'benefits require high efforts' are mentioned before this aspect.

		Introduction needs		Positive effects		Shortcomings	
OEM	1.	Reusability	71%	Quality	81%	Interoperability interfaces / Usability	50%
	2.	Shorter Development Time	64%	Reusability	72%	Distributed Development	44%
	3.	Reliability	61%	Reliability	68%	Version Management Support	42%
1st Level supplier	1.	Quality Improvements	72%	Quality	88%	Usability	59%
	2.	Shorter Development Time	71%	Reliability	81%	High efforts	50%
	3.	Reusability	64%	Traceability	79%	Training efforts / Interoperability interfaces	48%
2nd Level supplier	1.	Shorter Development Time	68%	Quality	86%	Interoperability interfaces	57%
	2.	Quality Improvements	67%	Development Time	77%	Semantic interoperability / Version Management / High efforts	53%
	3.	Maintainability	60%	Maintainability / Traceability	75%	Syntactic integration	50%

Table 4.2: Answers grouped by different value chain parties

In summary, the position in the value chain does not seem to affect the views on RQ1 to RQ5 substantially.

Company size

RQ1 - RQ4 do not show substantial differences between the three subgroups of company sizes: SME, Large Company and University/Research Institute. However, it has to be considered, that most of the surveyed subjects work at a large company (78%) (Cp. section 4.1). With respect to RQ1, SMEs use more eclipse-based tools than Matlab/Simulink/Stateflow and do less use differential equations in contrast to large companies and universities/research institutes. Further, SMEs use less MBE tools than non-MBE tools in contrast to the others. Concerning the usage of MBE (RQ4), the number of top answers differs in subgroups. SMEs mostly use MBE for behavioral consistency checks (9 out of 14), large companies for code generation (64 out of 87) and universities/research institutes for simulation (8 out of 11).

Regarding RQ5, most participants of large companies and SMEs think that MBE has a positive effect on development time (70% and 80%) in contrast to universities with only 43%. Moreover, 29% of university participants think that MBE has a partly negative effect on safety compared to only 2% of large companies and 0% of SMEs. A narrow majority of participants from universities/research institutes answered that MBE has a partly negative effect on confidentiality (33%). Only 17% think that it has a positive effect on confidentiality which is contrary to the other subgroups.

67% of subjects at universities/research institutes introduced MBE because of a need for formal methods but only 36% of SMEs and 30% of large companies adopted it for this reason. However, universities' top answers concerning the needs of introduction are reusability (80%), cost savings (71%), safety and reliability (each with 70%). Participants of large companies answered the need for better reusability, development time (each with 69%) and quality improvements (67%).

Moreover, some differences between the subgroups exist with regard to the top answers of the shortcomings. Main shortcomings of SMEs are high effort for training developers (71%) and difficulties of integration with existing legacy code (67%) and benefits require high efforts (51%) whereas large companies think that difficulties with interfaces to interoperate with other tools (49%) and usability problems (44%) are the most substantial shortcomings. Research institutes main challenges are difficulties of syntactic and semantic integration with other tools (each with 100%), high overhead and difficulties with variability management support (each with 67%). However, the results for RQ5 are summarized in Table 4.3. Summing it up, there are some differences in the ranking of the answers, but no major contradictions exist.

		Introduction needs		Positive effects		Shortcomings	
University	1.	Improve reusability	80%	Reusability	100%	Semantic interoperability, syntactic integration	100%
	2.	Save costs	71%	Availability	83%	Variability management	66%
	3.	Improve reliability / improve safety	70%	Formal method adoption	75%	Integration legacy code / requires high efforts	50%
SME	1.	Shorter development time	77%	Quality	82%	Training effort	71%
	2.	Improve reliability	75%	Development time	80%	Integration legacy code	67%
	3.	Improve quality	67 %	Formal method adoption	78%	Requires high efforts	55%
Large company	1.	Improve reusability	69%	Quality	89%	Interoperability interfaces	49%
	2.	Shorter development time	69%	Reusability	73%	Usability issues	44%
	3.	Improve quality	67%	Development time / reliability	70%	Variability management	43%

Table 4.3: Answers grouped by different company sizes

Target product

With respect to participants distribution of the developed target product, most of surveyed subjects use MBE to develop commercial products (46 in large scale, 19 in medium scale and 8 in small scale), 23 use it for research demonstration and 9 for non-commercial products as discussed in section 4.1. RQ1-RQ4 do not show considerable differences between these subgroups. One aspect that has been noticed, is that participants using MBE for large scale productions apply more Matlab/Simulink/Stateflow (28) than Eclipse based tools (10) in contrast to the other subgroups.

Concerning RQ5, the most common answers for the introduction needs are very similar for every subgroup and correspond to the answers discussed in section 4.6. Nevertheless, there are two exceptions. First, most common answer of companies that use MBE for small scale production is 'need to improve safety' Secondly, in-house product developers think that traceability was a important need for introducing MBE (third common answer). These two needs are not in the top answers of the collectivity.

With regard to the effects and the shortcomings of MBE, there are neither special differences between the subgroups. Top answers of all subgroups represent one of the six most given answers (cp. section 4.6). However, the order of the answers is different between subgroups (see Table 4.4).

		Introduction needs		Positive effects		Shortcomings	
Research demon-strator	1.	Improve reliability	76%	Reusability	92%	Syntactic integration	85%
	2.	Shorter development time	75%	Reliability / Formal method adoption	91%	Interoperability interfaces	71%
	3.	Improve quality	73%	Integrity / Availability	88%	Variability management	63%
In-house product	1.	na		na		na	
	2.	na		na		na	
	3.	na		na		na	
Small scale product	1.	na		na		na	
	2.	na		na		na	
	3.	na		na		na	
Medium scale product	1.	Shorter development time	83%	Quality	93%	Training effort	69%
	2.	Improve quality / improve reliability	76%	Maintainability	76%	Tool usability	62%
	3.	Improve maintainability	67%	Reliability	73%	Tool customization / interoperability interfaces	56%
Large scale product	1.	Shorter development time	75%	Quality	87%	Interoperability interfaces	44%
	2.	Improve maintainability	71%	Development time	84%	Variability management	44%
	3.	Improve reusability	68%	Reusability	79%	Semantic interoperability	41%

Table 4.4: Answers grouped by different target products

All in all no essential differences between the analyzed subgroups could be detected. In this paper, we only analyzed subgroups where we most likely expected some differences. Nevertheless, in case someone is interested in analyzing further subgroups, we provide the raw data as described in Section 3.

5 Conclusion and Future Work

The presented results strongly confirm that indeed Model-Based Engineering is widespread in the embedded domain. Models are clearly not only used for informative and documentation purposes; they are key artifacts of the development processes, and they are used for, e.g., simulation and code generation. Other widespread uses of significant importance are behavioral and structural consistency checking, as well as test case generation, traceability and timing analysis. While survey respondents reported mostly positive effects of Model-Based Engineering, the data also suggests some common and major challenges for MBE that need further attention. These include effective adoption among developers to reduce effort-intensive activities currently needed to realize benefits of MBE. Furthermore, some challenges concern the specific tools adopted and their interoperation. The collected data shows also that no essential differences between various subgroups of users exist. More precisely this means that methods, languages, tools as well as effects and shortcomings of MBE are not strongly dependent on domain, position in value chain, company size or developed target product.

In the future, we plan on following-up the results of this study by replicating the survey with a different target group in the embedded domain to validate the identified results. Furthermore, a validation of some effects of the introduction of Model-Based Engineering can be performed by collecting quantitative data in a company which introduces a MBE approach. Tool interoperability was mentioned as one of the key shortcomings, which fits well with the goals of the research project CRYSTAL where we focus on interoperability.

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A Online Survey

0% completed

Rationale:
The aim of the questionnaire is to get an overview of the state of practice and the needs regarding model-based engineering and model-based system analysis.
This means that we want to know if model-based engineering is used in practice, how it is used in development, and how models are used for a first verification/validation of the system.

Expected result:
The evaluation of the questionnaire should result in the derivation of open issues which should be covered within the CRYSTAL project funded by the EU.

Target group:
We want to target software architects, developers, project managers, system engineers, etc. from OEMs and suppliers from the embedded systems domain. This can, but not necessarily has to, include safety-critical systems.

Additional information:
The survey consists of 24 questions and will take approximately 15 minutes to answer. Additional 'other' fields can be added dynamically to some questions by filling in answers into the existing 'other' fields.
In some questions we ask about 'your division/department'. With the term division/department, we refer to organisational units with up to 50 people.

Your answers are treated completely anonymous.

The survey ends on 1st December 2013.

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20% completed

Context (Domain/Products/Terms)

1. In which company do you work?

2. Is your company a Small or Medium Enterprise (SME, <= 250 employees) or a large company (or part of)?

- SME
- Large Company
- University/Research Institute
- Other:

3. In which domain do you work?

- Automotive
- Avionics
- Healthcare
- Rail
- Domain independent
- Defense
- Telecommunications

Other:

4. What is your company's position in the value chain?

- OEM (Original Equipment Manufacturer – refers to a company that makes a final product for the consumer marketplace)
- First tier supplier (a company that is a direct supplier to OEMs)
- Second tier supplier (a company that is the key supplier to tier one suppliers)

Other:

5. How large is a work group within a typical project in your company?

- 0-5 persons
- 5-15 persons
- >15 persons

6. What are your main working tasks?

Architecture definition: ***We define architecture as the coarse grained structure of the system and how the different parts interact. An architectural configuration consists of independent components (software (including libraries) or hardware), interfaces of the components and connectors, which connect the components via their interfaces.***

Design definition: ***In contrast to the architecture, the design is concerned with the details inside one component.***

- [ ] NASA Safety Critical Guidelines (NASA-DB-1040)

Other:

d. Healthcare

- [ ] IEC62304
- [ ] IEC62061
- [ ] IEC 60601

Other:

e. Others

Other:

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40% completed

CRYSTAL

Model-based engineering

8. Which of the following answers conform to your view of model-based engineering?

Model-based engineering...

- ☐ is a new software and systems development paradigm.
- ☐ is the application of visual modeling.
- ☐ is in contrast to document-based, code-centric engineering.
- ☐ uses models for all different artifacts of the development process.
- ☐ makes use of problem-oriented structures.
- ☐ is a technique to speed up the design process.
- ☐ is a method to reduce the probability of systematic error.
- ☐ allows for fast formal and simulative validation.
- ☐ is designing a solution in tight loop with a virtual environment.
- ☐ places models in the center of the development process.

Other: ____________

9. Please rate your experience with model-based engineering.

- ○ Newbie (< 1 year)
- ○ Moderate experience (1-3 years)
- ○ Highly experienced (> 3 years)

10. When did your division/department start applying model-based engineering?

- ○ 10 or more years ago
- ○ 1 – 5 years ago
- ○ 5 – 10 years ago
- ○ 1 month – 1 year ago
- ○ We haven’t applied model-based engineering, yet.
- ○ I don’t know

11. When did you personally use model-based engineering the last time?

- ○ 10 or more years ago
- ○ 1 – 5 years ago
- ○ 5 – 10 years ago
- ○ 1 month – 1 year ago
- ○ I am still using it
- ○ I have never used model-based engineering

12. Do you see yourself as a promoter or opponent of model-based engineering?

- ○ Promoter

15. What were the effects of introducing model-based engineering in your division/department?

	highly negative		no effect		highly positive	I don't know
Quality	○	○	○	○	○	○
Development time	○	○	○	○	○	○
Efficiency of resulting code	○	○	○	○	○	○
Cost	○	○	○	○	○	○
Formal method adoption	○	○	○	○	○	○
Standard conformity	○	○	○	○	○	○
Traceability	○	○	○	○	○	○
Reliability	○	○	○	○	○	○
Availability	○	○	○	○	○	○
Safety	○	○	○	○	○	○
Integrity	○	○	○	○	○	○
Maintainability	○	○	○	○	○	○
Confidentiality	○	○	○	○	○	○
Reusability	○	○	○	○	○	○

Additional effects and their magnitude:

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60% completed

Model-based engineering - Part II

16. Which modeling environment do you use personally and which one is used in your division/department?

	Personal use	Division /Department
None	☐	☐
Rational Rhapsody	☐	☐
Artisan Studio	☐	☐
Enterprise Architect	☐	☐
Matlab / Simulink / Stateflow	☐	☐
UPPAAL	☐	☐
SCADE	☐	☐
ASCET	☐	☐
ASD:Suite	☐	☐
Labview	☐	☐
DYMOLA	☐	☐
SimulationX	☐	☐
Papyrus	☐	☐
Eclipse-based tools	☐	☐
In-house tool	☐	☐

Additional modeling environments for personal or division/department use:

17. Which modeling language(s) do you use personally and which one(s) are used in your division/department?

	Personal	Division /Department
None	☐	☐
UML	☐	☐
SysML	☐	☐
Modelica	☐	☐
Altarica	☐	☐
MARTE	☐	☐
Standard Domain-specific language/profile (e.g. EAST-ADL, AADL):	☐	☐
Company-internal approach/language:	☐	☐

Additional modeling languages for personal or division/department use:

Safety aspects	☐	☐

Additional functional aspects models are used for personally or within division/department:

20. How would you compare <u>your usage</u> and the usage within <u>your division/department</u> of model-based and non model-based tools for performing engineering activities?

	Personal	Division /Department
I/We do not perform engineering activities	○	○
I/We do not use model-based engineering tools	○	○
I/We use model-based engineering tools less than non model-based engineering tools	○	○
I/We use model-based engineering tools more than non model-based engineering tools	○	○
I/We use only model-based engineering tools	○	○

21. To what extent do the following potential shortcomings apply to the applied modeling approach?

	Does not apply at all		Partly applies		Fully applies	I don't know
Benefits require high efforts	○	○	○	○	○	○
High overhead involved	○	○	○	○	○	○
Many usability issues with the tools	○	○	○	○	○	○
Impossible/difficult to customize tools	○	○	○	○	○	○
Many limitations or difficulties on what can be expressed within the tools	○	○	○	○	○	○
Lack of proper semantics	○	○	○	○	○	○
Lack of completeness and consistency checks	○	○	○	○	○	○
Lack of model checking capabilities	○	○	○	○	○	○
Difficulties with integration into development process/current way of work	○	○	○	○	○	○
Difficulties with interfaces to interoperate with other tools (e.g. model exchange)	○	○	○	○	○	○
Difficulties of syntactic integration (e.g., different modeling language with different formats) with other tools	○	○	○	○	○	○
Difficulties of semantic interoperability (e.g., different definitions for the semantic of the modeling language) with other tools	○	○	○	○	○	○
Difficulties for distributed development	○	○	○	○	○	○
Difficulties/lack of traceability support	○	○	○	○	○	○
Difficulties with code generation capabilities	○	○	○	○	○	○

Difficulties of integration with existing legacy code	○	○	○	○	○	○
Difficulties with variability management support	○	○	○	○	○	○
Difficulties with version management support	○	○	○	○	○	○
High effort for training of developers	○	○	○	○	○	○

Additional shortcomings and their magnitude:

22. For which purpose does your division/department currently use models and what do you personally think models should be used for?

	Current use	Desired use
Not used	☐	☐
Information/documentation	☐	☐
Simulation	☐	☐
Code generation	☐	☐
Test-case generation	☐	☐
Structural consistency checks	☐	☐
Behavioral consistency checks	☐	☐
Formal verification/theorem proving	☐	☐
Safety compliance checks	☐	☐
Timing analysis	☐	☐
Reliability analysis	☐	☐
Traceability	☐	☐

Additional current or future model usages:

23. Which types of integration mechanisms do you currently use and which ones should be used in the future?

	Current use	Desired use
No automatic integration	☐	☐
(Hyper-) Links	☐	☐
Common database/model accessed by different tools	☐	☐
Export/Import via defined file formats	☐	☐
Tool adapters/plug-ins	☐	☐
Message passing between tools	☐	☐

Additional types of integration mechanisms which are or should be used:

24. In which phases of the development process are you using model-based engineering?

- ☐ Requirements Analysis
- ☐ System Architecture
- ☐ Subsystem/Component Design
- ☐ Implementation
- ☐ Subsystem/Component Test
- ☐ Integration Test
- ☐ System Test

Other: ______

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80% completed

Thank you very much for taking the time to participate in our survey.

25. If you want to be informed of the results of this study, please enter your email below.

The e-mail address can't be traced to the entered data. Therefore, entering your e-mail does not affect the anonymity of this survey!

Email

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