Dr. Andreas Jedlitschka
Jessica Jung
Dr. Constanza Lampasona

16

Evaluation Summary

A survey conducted by the developers of the SPES modeling framework at the beginning of the project revealed four high-level industry challenges that were to be addressed. Several evaluation studies were conducted in the application domains, aiming at investigating the contributions of the SPES modeling framework towards solving these industry challenges. The results of these studies are summarized for each challenge. The main results indicate that the SPES modeling framework is applicable in the chosen application domains. However, additional efforts for adapting the SPES modeling framework were reported to be necessary. In summary, the SPES modeling framework is well-aligned with regard to the industry challenges. Future evaluations would be necessary to investigate cost benefits and the efficiency of the approach. In addition, evaluation results show that the SPES modeling framework has the potential to provide a stable foundation for future evolutions of model-based approaches for the development of embedded systems. The current need and future relevance of model-based development approaches for embedded systems is supported by results from a survey.

K. Pohl et al. (eds.), *Model-Based Engineering of Embedded Systems: The SPES 2020 Methodology*,
DOI 10.1007/978-3-642-34614-9_16,

16.1 Introduction

Motivation: empirical studies as decision support

Decision makers in embedded system development require evidence about technologies to enable them to make an informed decision when new development technologies are to be introduced. However, this evidence must be obtained systematically, i.e., the studies have to be planned according to goals, conducted, analyzed, and reported so that the results are conclusive and the studies can be replicated. In Chapter 10, we presented an overview of the evaluation strategy that was to be used to evaluate the SPES modeling framework.

Matching the SPES principles to the SPES modeling framework

Industry challenges for the engineering of software-intensive embedded systems were identified by means of a set of interviews conducted with project partners, as well as a comprehensive state-of-practice study (see Chapter 2, [Sikora et al. 2012]).

We summarized the given industry challenges, identifying four high-level challenges:

- Model technical systems and their interaction
- Provide traceable and seamless support for all life cycle phases
- Address and verify system properties early
- Address safety, standard compliance, and certifiability

Based on these challenges, principles for the SPES modeling framework were derived (see Chapter 3):

- Distinction between problem and solution
- Distinction between logical and technical solution
- Explicit consideration of system decomposition
- Seamless model-based engineering
- Continuous engineering of crosscutting system properties

The SPES principles have to be addressed by the SPES modeling framework. For the SPES modeling framework, the following properties were defined:

- Scalability
- Productivity
- Division of labor
- Ease of use

For the SPES models the following properties were defined, describing the extent to which they support system development:

- Handling of complexity
- Maintainability
- Reusability
- Consistency between different models (in all directions of the SPES modeling framework)
- Reduction in fault tendency

The high-level evaluation goals addressed in the evaluations in the application domains were quality, efficiency, and usability.

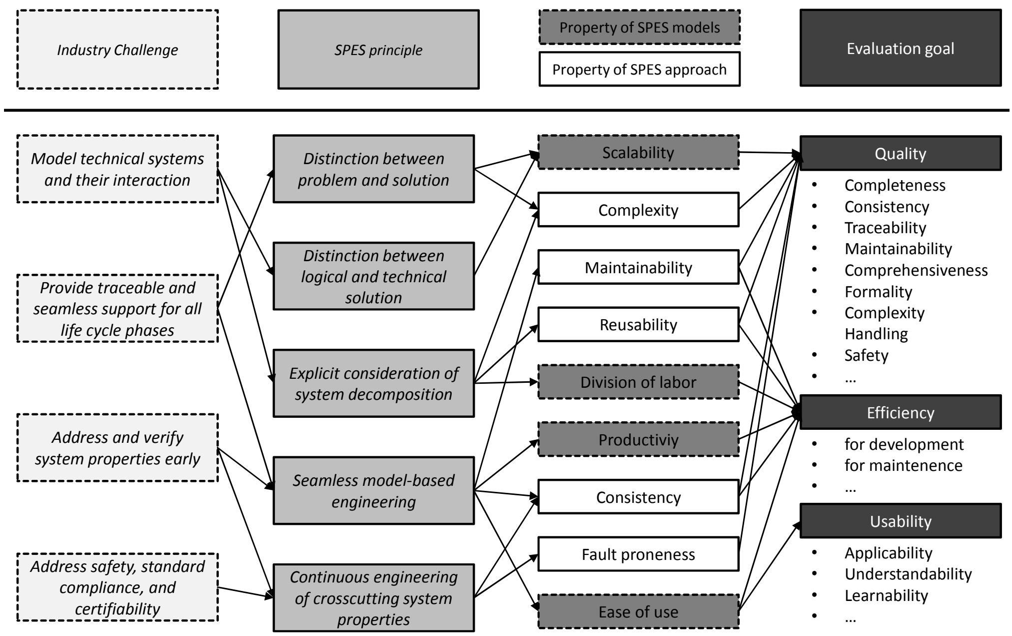

Fig. 16-1 *Matching SPES principles to the properties of SPES modeling framework and to the evaluation goals*

Fig. 16-1 presents the relationships between the summarized industry challenges, SPES principles, properties of the SPES modeling framework and inherent models, and evaluation goals. The evaluation in the application domains assessed the SPES modeling framework with regard to specific attributes listed as evaluation goals. For example, with regard to the evaluation goal quality, attributes such as a model's completeness, its consistency, and traceability of artifacts were studied. Also, the question of the extent to which the SPES modeling framework had an impact on the development or maintenance efficiency was investigated. In terms of the evaluation goal usability, the SPES modeling framework was evaluated concerning aspects such as applicability, understandability, and learnability. A selection of evaluation studies were reported in previous chapters.

In the remainder of this chapter, we summarize the results from the studies that were conducted to evaluate the SPES principles and their implementation in the SPES modeling framework. Further, we discuss results from a survey that support current and future relevance of model-driven development (MDD).

16.2 Conclusions from the Evaluations

Overview and conclusions of evaluation studies in SPES

To assess the extent to which the SPES modeling framework and models fulfill industrial challenges, the evaluation studies in the application domains addressed both the level of abstraction and the viewpoints. Fig. 16-2 shows that the evaluation studies cover the whole SPES modeling framework.

A vertical bar indicates that for an empirical evaluation of an approach, the approach was applied across several abstraction layers within a specific viewpoint, for example, the requirements viewpoint. A horizontal bar indicates that the focus of the study was across viewpoints. For the details of the evaluations we refer to Chapters 11 through 15.

The general purpose of the evaluation studies was to investigate whether and under what conditions the SPES modeling framework can be applied in the context of the specific application domain (cf. domain-specific challenges). Domain-specific requirements have influenced both the adoption of the SPES modeling framework as well as the design of the evaluation studies. These domain-specific requirements come from:

- Disciplines with heterogeneous engineering approaches, such as mechanics, electrics, and software, that need to interact in the automation (cf. Chapter 11) and automotive domains (cf. Chapter 12)
- Disciplines with the need for certifiable systems in the avionics (cf. Chapter 13) and healthcare domains (cf. Chapter 15)
- Disciplines with the need for flexible handling of massively distributed systems in the energy domain (cf. Chapter 14).

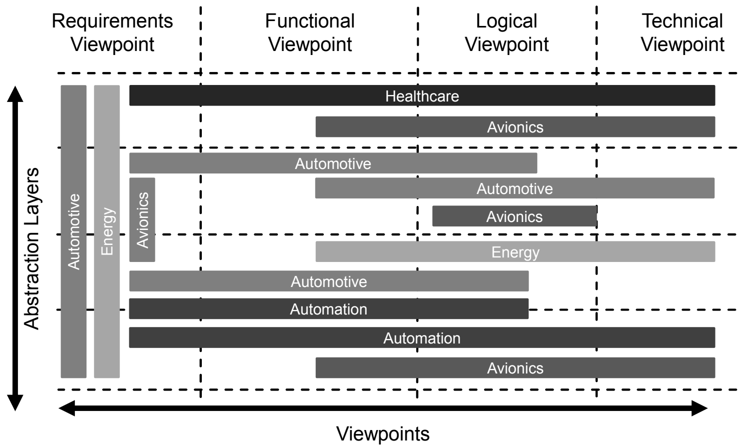

Fig. 16-2 *Placing the evaluation studies within the SPES modeling framework*

Summary of results of the evaluation studies

Most studies addressed the question of whether the SPES modeling framework can be applied (applicability) in the context of the specific domain. All domains report that the SPES modeling framework and inherent models are applicable. Nevertheless, a need for adaptation and a detailed guideline was reported. Some possible adaptations have been exemplified, e.g., in Section 14.4.1. Learnability of the technologies and understandability of the resulting documents was also perceived as positive by participants. However, in a few cases, explicit improvement suggestions, in particular regarding the transfer into daily practice, were given (e.g., see Section 12.3).

In the following, we summarize the results of the evaluation studies from the perspective of the high-level industry challenges.

Model technical systems and their interaction: Each of the five application domains applied the SPES modeling framework to several (domain-specific and typical) case studies. The case studies successfully demonstrated that the SPES modeling framework addresses this challenge. For example, in the automation domain, several types of systems were successfully integrated by mapping SPES principles to domain-specific modeling languages. In the avionics domain, we successfully showed that systems engineering and safety engineering can be integrated more smoothly by employing the SPES modeling framework. As can be concluded from Fig. 16-2, much emphasis was given to the requirements viewpoint. This is quite obvious, because this viewpoint addresses also understanding of the system to be developed and a common language for stakeholders involved. Results from the case studies demonstrate that the SPES modeling framework supports system understanding.

Provide traceable and seamless support for all life cycle phases: The challenge of horizontal integration (i.e., seamless methodological and tool support) of the SPES modeling framework (i.e., across several viewpoints) was addressed in all domains. As shown in Fig. 16-2, all domains provide case study results demonstrating how they employed the SPES modeling framework. Although the general results provide supporting evidence, the level of integration is different. Whereas for the automotive domain, seamless integration was successfully demonstrated for approach and development tools, the healthcare domain recognizes a deficiency with regard to supporting tools (see Chapters 12 and 15, respectively). Results reported from the case study in the avionics domain provide the insight that the integrated design and safety modeling allows systems and software engineers to work seamlessly on the same model (see Chapter 13). In addition, the results show that parts of the verification cases can be generated from formalized requirements.

Address and verify system properties early: Several studies investigated aspects of quality (cf. Fig. 16-1). With regard to the question of whether a certain level of product quality is achieved using the SPES modeling framework, we can summarize that the methods specifically addressing a certain quality aspect such as completeness, consistency, safety, or traceability fulfilled users' expectations. In particular, approaches addressing requirements' vertical traceability were successfully investigated, e.g., in the automotive, avionics, and energy domains (see Chapters 12 through 14 respectively). Results from a case study on an extended requirements process model in the automotive domain show a shift of effort towards earlier phases. Similarly, system simulation as a means for early verification was successfully integrated and employed in cases studies, in particular in the automotive and energy domain.

Address safety, standard compliance, and certifiability: Within the automotive, avionics, and healthcare domains in particular (cf. Chapters 12 through 14), the topics of safety, standard compliance, and certifiability are highly relevant. Therefore, these topics were also addressed in the case studies, e.g., a case study in the automotive domain demonstrated that the logical architecture can be automatically transformed into AUTOSAR application components and can be transferred to AUTOSAR basic software configurations.

In the avionics domain, it was found that the concept for the integration of safety cases as argumentation support for the certification authority showed a potential towards automated certification of safety-critical systems.

The integrated design and safety modeling showed that systems and software engineers can work seamlessly on the same model.

Transferability of the results across domains: As can be seen from previous chapters, different aspects of the SPES modeling framework were evaluated in different domains. For example, the automotive domain – among other things – focused on functional correctness and completeness in early phases as well as traceability (see Chapter 12), while the avionics domain focused on safety and verification (see Chapter 13). The results indicate that the transfer across all domains is possible in principle, but required adaptations according to the characteristics and challenges of the specific domains, e.g., in the automation domain to cope with different modeling languages of engineering disciplines involved, in the automotive domain to manage variants, and in the avionics domain to address safety and certification.

Open topics and future work: To provide decision-makers with even better guidance regarding the benefits or shortcomings of the SPES modeling framework, additional information, in particular, business-relevant aspects such as the costs and efficiency of methods, should be gathered by systematic empirical evaluation. However, this would require access to historical project data, serving as a baseline, and a set of real projects in which the SPES modeling framework is applied. The results of these projects would then be compared against the baseline. The data is hard to obtain due to confidentiality constraints. Furthermore, access to real projects often proved to be difficult due to the scheduling and alignment restrictions of those projects.

16.3 Relevance of Model-Driven Development

Survey results: major benefits of MDD for both industry and academia

To investigate the relevance of model-driven development (MDD), a survey was conducted [Lampasona 2012]. The questionnaire consisted of 87 items and was divided into six parts, including demographics, importance of MDD today, importance of MDD in the future, and expectations of MDD. The survey was designed taking into account two specific groups: participants from industry (both development staff as well as executive positions were included) and from academia, and 127 people were invited to participate. Of those, 64 answered the questionnaire.

The results show that MDD is more important in contemporary software engineering research than for current business objectives. For managerial staff, on average, MDD is equally important in both research and business. However, a vast majority agreed that the future of software engineering lies in MDD. In this case, half of the business executives strongly agreed, others agreeing mostly or answering neutrally on this issue.

Furthermore, we asked participants to judge the extent to which they expect different properties from MDD. As can be seen from Fig. 16-3, improving quality and reuse, complexity management, and reduced development costs are the issues that both researchers as well as practitioners expect the most benefit from by using MDD.

Finally, we asked an open question about the expectations of participants with regard to MDD. Out of 185 responses, the most frequently mentioned points were: improved validation and verification (19 responses), shorter development times (19), increased automation (15), better quality (16), and reduced costs (11).

In summary, we can say that model-based development is not only economically relevant, but is also expected to introduce major benefits for both industry and academia. In the SPES 2020 project, we have laid the foundation for successful model-based engineering of embedded systems, but there is still much to be done.

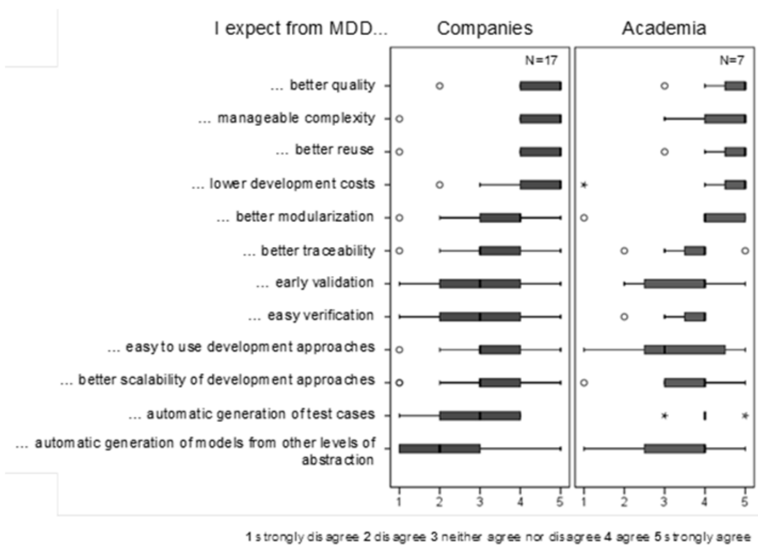

Fig. 16-3 *Expectations from MDD of practitioners and academics*

16.4 Summary

Positive results from individual evaluations: SPES approach and adaptable and applicable models

The predominantly positive results from the individual evaluations indicate that the SPES modeling framework and its inherent models address the industry challenges. Furthermore, the case studies in the application domains showed that the SPES modeling framework and models are adaptable to and applicable within the application domains. The SPES modeling framework, with its abstraction layers and viewpoints, helped to close existing gaps in systems and software modeling practice by providing, e.g., a better understanding of how to refine and to decompose complex systems and how to describe the relationship between artifacts created. These results are underlined by results from a survey that show that MDD is becoming more and more relevant. However, questions regarding the approach's cost-efficiency and impact on the development schedule have to be answered by future empirical studies.

16.5 References

[Lampasona 2012] C. Lampasona: Umfrage SPES 2020: Relevanz, Zukunft und Stellenwert modellbasierter Softwareentwicklung. Project Deliverable of SPES 2020. Available at spes2020.informatik.tu-muenchen.de/results/ZP-AP6.D6.2.B1 MDD Umfrage_final.pdf

[Sikora et al. 2012] E. Sikora, B. Tenbergen, K. Pohl. Industry needs and research directions in requirements engineering for embedded systems. In: Requirements Engineering Journal, Vol. 17, No.1, 2012, pp. 57-78.

16.6 Acknowledgements

We specifically acknowledge the contributions of Marcus Ciolkowski, who led the evaluation work in SPES 2020 until the end of May 2011. Special thanks go also to Sabine Nunnenmacher for her contributions in planning and conducting empirical studies and surveys in the first two years of SPES 2020. Last but not least, we also want to thank Sarah Tichy for her support in the statistical analyses of data obtained from the studies conducted, and Bastian Tenbergen for valuable comments and never-ending patience.