Jurnal Teknologi

Guideline for oriented Systems Engineering Process in small and medium sized enterprises

Anja Czaja[a]*, Roman Dumitrescu[b]

[a]Heinz Nixdorf Institute, Fürstenallee 11, 33102 Paderborn, Germany
[b]Fraunhofer Institute Institute for Production Technology IPT, Project Group Mechatronic Systems Design, Zukunftsmeile 1, 33102 Paderborn, Germany

Graphical abstract
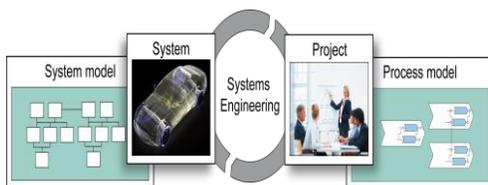
Abstract

Technical systems of tomorrow will go beyond current traditional mechatronics designs by incorporating inherent intelligence. This adds high demands on the product development process, such as the need for a comprehensive understanding of the system and consideration of the full product life-cycle. Systems engineering (SE) is an approach that has a potential to fulfill these requirements. However, until now it could not be applied through a wide range of different industries and segments, especially in small and medium sized enterprises. This paper discusses different obstacles for the use of SE and presents a concept for a systems engineering guideline to face these challenges. The aim of the systems engineering guideline is to enable a target-oriented application of systems engineering methods and tools. The objective is to overcome the *barriers of introduction* of SE for enterprises. It links a design process to methods and tools in the field of systems engineering.

Keywords: Systems engineering, small and medium sized enterprises, tailoring

1.0 DEVELOPMENT OF INTELLIGENT TECHNICAL SYSTEMS

The mechanical engineering industry and related industries, such as the auto-motive industry, are undergoing a massive shift from classic mechanic-centered products to mechatronics. Technical systems of tomorrow will go beyond current mechatronics by incorporating inherent intelligence. Information technology and non-technical disciplines, such as cognitive science, neurobiology and linguistics, are developing a variety of methods, technologies and procedures that integrate sensory, actuators and cognitive functions into technical systems. Such systems are called Intelligent Technical Systems.

Intelligent technical systems make products and production systems more user-friendly, reliable and resource efficient, with the benefit stemming from interaction between different components and technologies. This places high demands on the product development process, such as the need for a comprehensive understanding of the system and consideration of the full product life cycle. The development of these systems can no longer be analysed from the perspective of an individual specialist discipline; the established discipline specific methodology reaches its limits as it does not consider the interaction of the disciplines involved. Furthermore, interdisciplinary approaches for the design for mechatronic systems, like e.g., the VDI-guideline 2206 "design methodology for mechatronic systems", do not meet the challenges of future systems. They do not consider all aspects of complex technical systems collectively. Systems engineering (SE) is an approach that has the potential to satisfy these requirements. Nonetheless, until now it could not become established throw a wide range of different industries

and segments, especially in small and medium sized enterprises [1].

2.0 SYSTEMS ENGINEERING

Systems engineering is a consistent and multidisciplinary discipline for developing technical systems that consider all aspects. It focuses on the multidisciplinary system and covers the entirety of all development activities. Therefore, interdisciplinarity and the targeted are holistic analysis of problems are paramount. Systems engineering addresses the system to be developed and the associated project in equal measure. Beyond the central tasks of product development, it considers the mutual dependencies of these activities [2] (Figure 1).

Figure 1 The concept of systems engineering

According to the high range of mechatronics and intelligent technical systems, there are many different norms, standards, and guidelines that need to be considered in the context of systems engineering. In the following, selected norms and guidelines, as well as further procedure models for multidisciplinary development are presented

The norms, standards and guidelines of SE are largely based on best practices and were drafted by representatives/ institutions based on their experience, like e.g., from aerospace industry). This means that the standards only contrast with each other in particular aspects and address different perspectives. They do not offer sufficient support for the widespread application of systems engineering. It is difficult to gain an overview of how norms interact to bring systems engineering closer to the user. For example the ISO/IEC 15288 "Systems development - the system life cycle and its processes" positions the topic of systems engineering in Europe for large projects and companies. The following four views are analyzed in this norm: (1) agreement processes, (2) enterprise processes, (3) technical processes and (4) project-specific processes. The ISO/IEC29110 of 2014 for software and systems engineering is an interpretation and adaption of the ISO/IEC 15288 and focuses on small and medium sized enterprises. The norm defines SME profile-groups and provides different management and engineering guidelines for each profile-group. Until now, only parts of the norm are published. For SE, only the guideline for the profile-group basic is available [4, 5, 6]. The VDI Guideline 2206 "Design methodology for mechatronics systems" describes a generic procedure for the development of mechatronischen systems. Basic element is the V-model, which is based on the software engineering V-model and was adapted for the development of mechatronic systems [10]. Aim of the system design is to establish a cross domain solution concept, which describes the main physical and logical operating characteristics of the future product. Based on that solution concept, further concretization usually takes places separately in the domains involved. In the system integration, the results are integrated to an overall system. The guideline focuses on mechatronic systems and does not consider the challenges of the development of intelligent technical systems enough, like e.g., the analysis of the entire product life cycle or product service combination.

Beside norms and standards, there are further procedure models in the context of systems engineering to by considered. Procedure models divide the design process in different development phases. They support to structure and organize the development procedure. The three level model of Bender is also a procedure model for the design of mechatronic systems, it is a concretization of the V-model and reduces the complexity by dividing the development task into system, subsystem, and component. The Collaborative research centre 614 "Self-Optimizing Concepts and Structures in Mechanical Engineering" developed a procedure model for the design of self-optimizing systems, it is also based on the V-model [11]. The focus lies on the special properties of self-optimizing systems. There is no established procedure model or guideline for the development of intelligent technical systems yet [13].

In the context of systems engineering, the procedure models of model based systems engineering (MBSE) need also to be considered. Model-Based Systems Engineering (MBSE) places a multidisciplinary system model in the center of the development. MBSE procedure models are mainly based on a MBSE model language, like e.g., SysML and the Object Oriented Systems Engineering Method (OOSEM) of INCOSE [12]. There is no standard MBSE methodology yet [3].

Beside MBSE methods, there are many different development methods, which can be classified as systems engineering methods. These methods focus on different topic areas, like e.g., requirements engineering, model-based systems engineering, virtual verification and validation, and integrative planning of the production, and address a variety of problems. There is a high number of tools to support the use of these methods and to make them more effective and efficiency. The difficulty lies in the selection of suitable methods, tools, and procedures.

3.0 OBSTACLES FOR THE USE OF SYSTEMS ENGINEERING

The survey "systems engineering in industrial practice" illustrates the capability of systems engineering and points out the current level of use of SE in practice. The study confirms discussed difficulties and shows different obstacles for the application of SE (Figure 2) [3]. Beside of large enterprises, more and more small and medium sized enterprises (SME) recognize that they need interdisciplinary approaches in their design process. But systems engineering is a large domain and it mainly offers only individual solutions and no holistic methodology. The interviewee point out the following obstacles in the application of systems engineering:

(1) Benefits not quantifiable: The benefits of systems engineering seem high, but cannot be sufficiently quantified. Projects must pay off immediately, but systems engineering requires high expenditure at the beginning. Management is unable to grasp the relation between the expenditure, which seems high initially, and the resulting benefits.
(2) Barriers to introduction: This concerns SE approaches as a whole, but also many partial aspects. Thus, companies find it difficult to recognize which changes and activities must be introduced, and when, where and how these are required. In this context, the lack of adaptability of SE approaches is also a problem. The approaches mainly fit to the structures of big enterprises or projects, like e.g., in the aerospace field, they do not consider the special parameters of small and medium-sized enterprises enough. In particular, for the sector of mechanical and plant engineering, the methods are still hardly comprehensible and understandable and the approaches are difficult to integrate into existing processes for enterprises.
(3) Insufficient expertise: This concerns all company divisions from management to specialists. All must have an understanding and awareness of systems engineering. Corresponding training expenditure must be scheduled for the current development team. There is a lack of expertise and awareness of the problem. Particularly in engineering training, there is still a considerable difference between the current courses offered and practical requirements. A majority of the courses offered are discipline-specific, which almost inevitably arise from the established faculty structures. Even the few current systems engineering courses do not cover the requirements of practical systems engineering. Moreover, are not sufficient to satisfy interdisciplinary requirements. The actual idea of systems engineering is rarely found in teaching.
(4) Not required for own products: Some companies feel that systems engineering is over-dimensioned for their own products. They have successfully marketed their products thus far enough. Therefore they see no need for SE in their company. There are many different hardly comprehensible and understandable methods, procedures, and tools in the context of systems engineering, which mainly fit to the structures of big enterprises or projects.
In addition, the no clear distinction of terms and an insufficient tool support cause problems for experts in practical use.
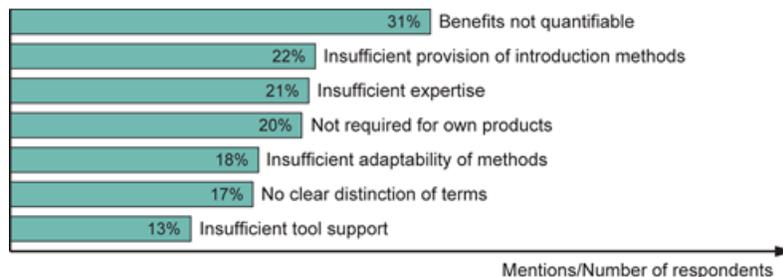

Figure 2 Obstacles in the application of SE [3]

All these aspects lead to impediments for the use of SE, especially in small and medium sized enterprises. They have to deal with limited recourses and need simple and oriented solutions.

4.0 GUIDELINE FOR ORIENTED SYSTEMS ENGINEERING PROCESS

The cross section project "Systems Engineering it's OWL" of the Leading- Edge Cluster Intelligent Technical Systems OstWestfalenLippe (it's OWL) faces this challenges. To support a performance

improvement by using systems engineering, particularly for machinery and plant engineering enterprises, a scalable systems engineering guideline gets build up. Therefore, the special characteristics of machinery and plant engineering need to be considered like e.g., resources, competences, etc.. The aim of the systems engineering guideline is to enable a target-oriented application of systems engineering methods and tools. The objective is to overcome the barriers of introduction of SE for enterprises. Therefore, the SE-guideline has to show which activities need to be introduced, and when, where and how these are required. It links a design process to methods and tools in the field of systems engineering (Figure 3). To remove the lack of adaptability of SE approaches, the guideline also has to provide practice-oriented tailoring mechanism. So that it supports the selection and combination of process action, method and, tools based on product, project, and organization parameters. The tailoring mechanism of the V-model XT can serve as a basis for that. Depending on the project parameters development activities, like e.g., early dependability analysis, to be performed are defined. The SE-guideline also addresses the problem of insufficient expertise in the companies by a systematic systems engineering database. The constituent parts of the SE-guideline represent a method database and a guide for selection and planning of the systems engineering methods throughout the whole product development process. The method database contains the description of systems engineering methods (at the present time it contains ca. 50 methods). There are many different development methods, which can be classified as systems engineering methods. The SE-guideline focuses on methods in the context of system design, system analysis, system integration and project management. To manage the method variety, the methods are characterized in profiles by input (e.g. development order) and output (e.g. principle concept) as well as a number of task- and capability-specific criteria such as the advantages/disadvantages (e.g. tool-independency), the expenditure of use (e.g. maintenance), the development phase (e.g. conceptual design), and relevant references (e.g. norms and standards). Each method profile has related support documents (e.g. templates) which simplify the application especially for people with less expert knowledge. Figure 3 shows the items of the method profiles. The item user describes the user's role in the development process and the necessary competences. Moreover, the relationship between the methods is specified with three categories (method A and B can be combined; method A and B are similar or alternative; method A is prerequisite for method B). There are many dedicated, commercial, and open source tools in the field of systems engineering, like e.g., for Model-based Systems engineering. To provide more transparency, a tool database supplies basic information for relevant tools. Therefore, not only the tools, but also the tool coupling is evaluated in the project. The SE guideline links the tools to the corresponding process and methods.

To define the requirements for the SE- guideline, we analyzed the design process for different cluster companies in workshops and interviews. To consider different development parameters, we regarded different product categories (subsystems, systems and networking systems) and different development types (e.g. standard products and customer specific products). Main result: The enterprises master the discipline specific processes very well, but they need support in the interdisciplinary development process, especially to keep their competitiveness.
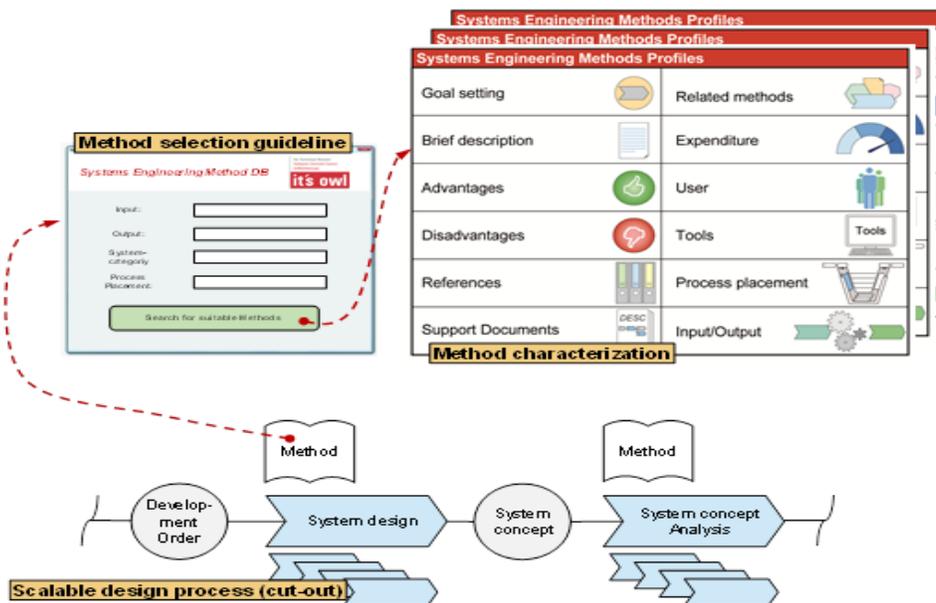

Figure 3 Overview systems engineering method profiles linked to design process

5.0 CONCLUSION AND OUTLOOK

The paper started with a brief overview about the challenges for the development of intelligent technical systems. Norms, standards and guidelines in the field of systems engineering were presented. Existing obstacles for the use of Systems Engineering especially for machinery and plant engineering and small and medium sized enterprises were discussed. Afterwards, a concept of a systems engineering guideline for the development of intelligent technical systems was presented. The elements were discussed and the first results were demonstrated by analyzing different process models, methods, systems engineering tools, and their relationships. The guideline concept will be extended in the project and validated with several cluster companies.

Acknowledgement

References

[1] Gausemeier, J., Dumitrescu, R. and Jürgenhake, C. Intelligent Technical Systems OstWestfalenLippe. In Proceedings of 2nd Joint Symposium on System-integrated Intelligence. *New Challenges for Product and Production Engineering (SysInt)*, July 2-4, Bremen, Germany, Nr. 15 , S. 17-26, 2. - 4. Jul. 2014. Elsevier Science.

[2] International Council on Systems Engineering (INCOSE). Systems Engineering Handbook. 2010. A Guide for System Life Cycle Processes and Activities. *International Council on Systems Engineering (INCOSE)*.

[3] Gausemeier, J., Dumitrescu, R., Steffen D. and *et al*. 2013. *Systems Engineering in Industrial Pratice*. Paderborn.

[4] Gaupp, F., Schulze, S-O. and Steffen, D. 2015. Die ISO29110- Möglichkeiten und Chancen für den Mittelstand. In: S-O. Schulze, M. Maurer (Eds.). *Tag des Systems Engineering* 2014, Carl Hanser Verlag, München. 351-359.

[5] Laporte, C., Houde, R. and Marvin, J. 2014. Systems Engineering International Standards and Support Tools for Very Small Enterprises. *24th Annual International Symposium of INCOSE*, Las Vegas, USA.

[6] ISO/IEC TR 29110-6-5-2:2014, Systems and Software Engineering- Systems Engineering lifcycle profiles for Very small Entities, *International Organization for Standardization/ International Electrotechnical Commission*, Switzerland.

[7] Verein Deutscher Ingenieure (VDI). 2004. VDI-Guideline 2206–*Design Methodology for Mechatronics Systems*. Beuth Verlag, Berlin.

[8] Gausemeier, J. and Vaßholz, M. 2014. Development of Self-Optimizing Systems. *In Dependability of Self-Optimizing Mechatronic Systems*. Kapitel 2. S. 25-36. Springer-Verlag. Heidelberg, Germany.

[9] Friedental, S. Moore, A. and Steiner, R. 2011. A Practical Guide to SysML. *The Systems Modeling Language*. Elsevier. Oxford.

[10] Birkhofer, H. 2011. *The Future of Design Methodology*. Springer. London.

[11] Pahl, G., Beitz, W., Feldhusen, J. and Grothe, K-H. 2007. *Engineering Design–A Systematic Approach*. 3rd English edition. Springer-Verlag, London.