Jurnal
Teknologi

Full Paper

POTENTIAL OF USING MODEL-BASED SYSTEMS ENGINEERING TO IMPROVE THE DEVELOPMENT PROCESS OF ENGINEERING-TO-ORDER PRODUCTS IN THE FIELD OF MACHINERY AND PLANT ENGINEERING

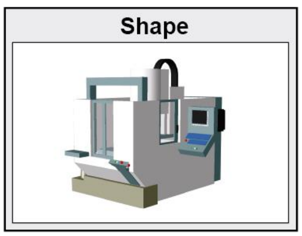
Article history
Received
13 February 2015
Received in revised form
29 April 2015
Accepted
31 May 2015

Martin Rabe*, Harald Anacker, Thorsten Westermann, Roman Dumitrescu

Fraunhofer Institute for Production Technology IPTProject Group Mechatronic Systems Design, Zukunftsmeile 1, 33102 Paderborn, Germany

*Corresponding author
martin.rabe@ipt.fraunhofer.de

Graphical abstract



Abstract

The machinery and plant engineering sector is faced with new challenges due to the shift to intelligent technical systems and the need to integrate intelligence into machines. In addition, machinery and plant engineering means customized orders which result in engineering-to-order products and a different development process comparing to serial production. The present contribution shows the potential of model-based systems engineering during the whole developments process from the acquisition to distribution and start-up.

Keywords: Engineering-to-order, model-based systems engineering, machinery and plant engineering, customized product engineering

1.0 INTRODUCTION

The aim of the research cluster it's OWL (Intelligent Technical Systems OstWestfalenLippe) is to develop intelligent technical systems and bring intelligence into machines and other systems. These innovations are often referred to as Industry 4.0. To gain this shift, advances in IT and mechanical engineering are needed as well as the close interaction between various disciplines like mechanics, electronics and software engineering [1]. Model-based systems engineering is an approach to master the increasing complexity within the development process and to merge the disciplines. To enable the cross-discipline cooperation, the core of the model-based systems engineering approach is a holistic model of the system. It provides different views of the systems and is comprehensible for all disciplines. Currently the method is used by large enterprises and organizations in the field of aerospace, aviation and automotive. These sectors are usually characterized through enormous R&D-budgets and long development times. But in fact this approach is also suitable for small and medium-sized enterprises (SME) with smaller development teams, lower budgets and short project durations. The region of the cluster it's OWL is characterized through many SME in the field of machinery and plant engineering. The results of a survey about systems engineering in industrial practice in Germany show that SME in this field lack in incentives to implement systems engineering methods and tools into their development process. Companies are convinced that systems engineering is over-dimensioned for their purpose and only beneficial for systems in the aerospace industry. The authors of the survey conclude that this is due to the lack of contact to systems engineering [2]. Indeed, in several it's OWL projects companies already discovered the benefits of using model-based systems engineering in their development process. This contribution shows the potential of model-based systems engineering to support the development processes of engineering-to-order products in the field of machinery and plant engineering.

2.0 CHALLENGES THROUGH CUSTOMIZED MACHINERY AND PLANT ENGINEERING

The benefits of model-based systems engineering within sectors like aviation and aerospace or automotive are obvious. The enormous complexity of the developed systems can be mastered which leads to more efficient product development processes and more effective decision-making [1]. Due to the integration of intelligent mechatronic features into production systems, SME in the field of machinery and plant engineering are faced with the same challenges. Increasing complexity and the need of cross-discipline cooperation between various disciplines lead to the same conclusion: Established design methodologies for mechanical engineering as well as other disciplines do not meet the new requirements to the product development process. The distinctions between these fields are customer-specific development, short project duration and low R&D-budgets.

The business models of typical SME in the field of machinery and plant engineering are individual systems customized exactly to the demand of the customer. According to the customer order decoupling point (CODP), these systems are engineering-to-order products. The CODP describes the point where specific customer requirements determine the product specifications. At this point in the value chain, customer driven production and forecast driven production are separated [3]. The customers in this field are manufacturer of different goods with the similarity to need perfectly adapted systems for their purpose. Every order leads to a new development project and since the purpose of a new machine is usually to increase the production capacity, costumers need their customized machines as soon as possible. To reach that goal, many challenges need to be mastered. Figure 1 shows the general development process of engineering-to-order products and four challenges to be improved by methods of model-based systems engineering.

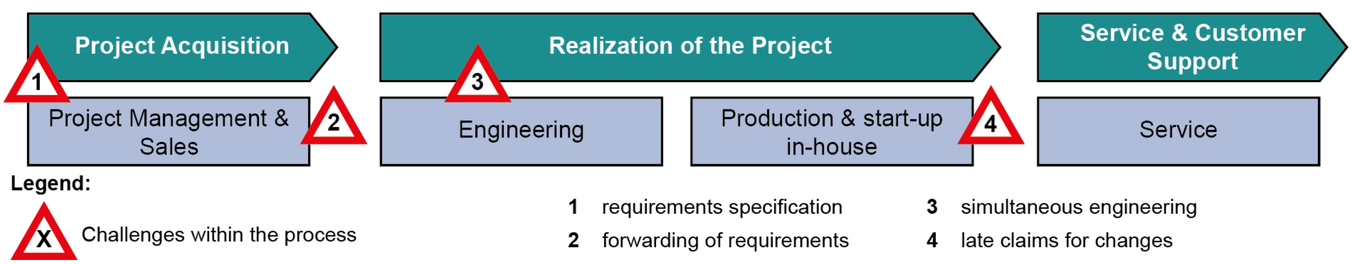


Figure 1 General development process of engineering-to-order products and its challenges

The first challenge occurs during the project acquisition. The technical sales need to identify exactly the customers' requirements. Late changes are time-consuming and expensive, what makes a well-working communication between supplier and customer very important. Document-based requirements specifications are often enormous and do not enable the supplier to understand the needs of the customer in a fair amount of time. The purpose of these comprehensive specifications is usually a legal issue (e.g. in the case of automotive manufacturer). In other cases, there is no specification available and the technical sales needs to acquire the requirements in interviews and document them in prose and drawings. The result is a bidding of the technical sales to the customer.

If an order is placed, the project manager begins to forward the requirements to different departments like mechanical design and software engineering which is the second challenge seen in Figure 1. The challenge is to ensure that all disciplines and departments reach the same understanding of the requirements and design an appropriate solution for the customer. A written documentation and certain drawings lead to misunderstandings and lasting coordination and changes. Software engineers conceive a technical drawing in a different way than mechanical engineers. Project manager and engineers do not have the time to handle an enormous requirement specification and rely on the most important requirements that are documented through the technical sales. The consequences are claims for changes because of non-compliance of the requirement specification. In the other case, if no requirement specification is available, claims for changes occur as well since the customer feels misunderstood about his communication with the technical sales. In both cases, the consequences are time-consuming and expensive changes as well as legal disputes in the worst case.

As the third chalenge, within the development process the engineering of the different disciplines do not proceed in parallel, although simultaneous engineering would reduce the development time. During the early stage of the engineering an interdisciplinary team of engineers work together and develop a first concept, the so called principle solution. Afterwards during the concretization the engineers of the involved disciplines do not work in a parallel manner. The software engineers, who are programming the machine controlling, rely on the mechanical design that is concretized first. Certain issues should have been regarded during the concretization of the mechanical design that occurs initially during the programming of the machine controlling. The software engineers need to work out a solution around the mechanical design instead of working together within the concretization. This problem will become more critically in the case of intelligent technical system where the amount of software within the machines is increasing enormously.

Lately many claims for subsequent changes occur during and after the start-up of the machine. This means that the machine is already delivered to the customer whose location is in a bad case far away from the location of the supplier. Mechanics and engineers need to travel to the location which is expensive and results in a long response time for the service. The forth challenge is a better understanding and coordination of the claimed changes to reduce service operations to a minimum.

To sum up, many problems occur because of misunderstanding between engineers of different disciplines as well as between supplier and customer. The aim of using a model-based approach within the order fulfillment and development process is to enable all participants in a successful communication. This can be reaches through a holistic view to the system. Since the budget of SME is strictly limited, the use of model-based systems engineering needs to be well suited to the process and benefits need to be perceivable immediately.

3.0 THE IDEA OF MODEL-BASED SYSTEMS ENGINEERING

Model-based systems engineering (MBSE) is the idea of describing a system in a holistic way beginning in the early phases of the product development and during the whole product lifecycle. Formalized models support the requirement engineering, design, analysis, verification and validation [4, 5]. The superior model leads to a common understanding for everybody involved at any stage of the product design and development. The method is well-known from the field of architecture, where a model of a building establishes a common understanding between all stakeholders but MBSE goes far beyond by providing different views to the system besides the design [1].

To describe a system with a system model, a method is needed to define the aspects of the product that have to be considered. Although, the method specifies the procedure how aspects are modeled and what information are needed. Despite the method, a language is needed to reach a formalized description and a common understanding [6]. In the following, we describe the method and language CONSENS for this purpose. To implement model-based systems engineering in a process, a tool is needed as well which has to be chose company-specific.

4.0 SYSTEMS ENGINEERING METHOD AND LANGUAGE CONSENS

CONSENS stands for CONceptual design Specification technique for the Engineering of complex systems and was developed at the Heinz Nixdorf Institute within the Collaborative Research Cluster (CRC) 614 [7]. The focus is the conceptual design phase of the product development and to show a systematic way to specify the system model involving all participating disciplines.

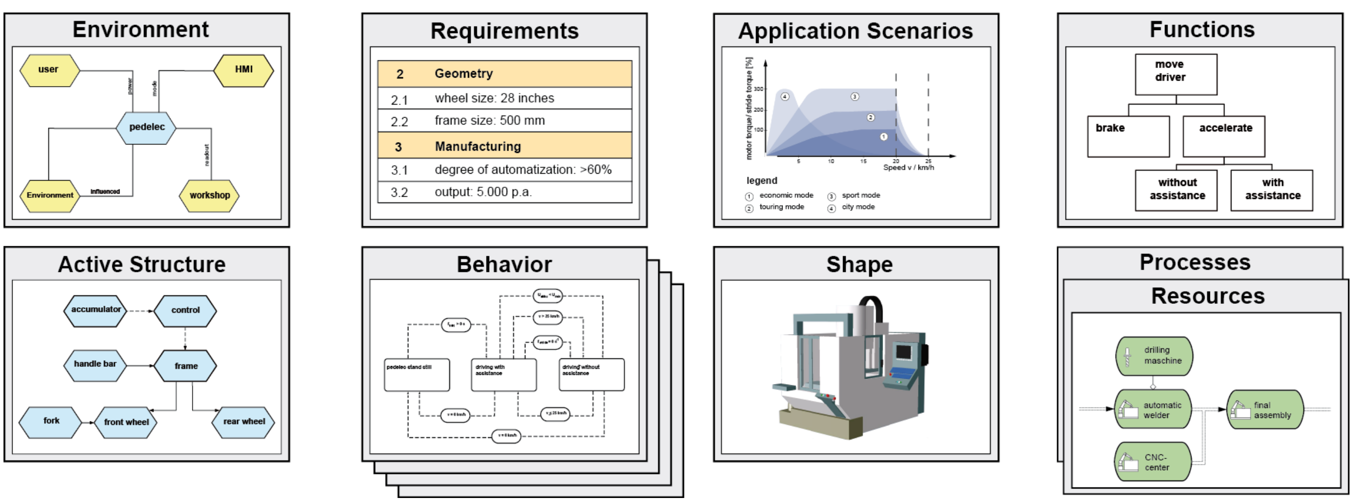


Figure 2 Partial models of CONSENS for the domain-spanning description of a system

Different partial models lead to different views to the system. The following aspects need to be taken into account: requirements, environment, application scenarios, functions, active structure, behavior and shape (Figure 2).

Although it can be extended through aspects concerning the production system of the regarded system like processes and resources. The partial models are computer-intern represented whereby this is tool-independent.

5.0 POTENTIALS FOR USING MODEL-BASED SYSTEMS ENGINEERING TO SUPPORT THE DEVELOPMENT PROCESS

Regarding the challenges through customized machinery and plant engineering, a crucial issue is a lacking common understanding of the systems. This concerns the engineers of the supplier as well as the customer. Like mentioned before, engineering-to-order means a specific solution that meets exactly the costumers requirements. But in fact most suppliers in the machinery and plant engineering sector possess a core business that results in reusing parts of the solution in every project. Using model-based systems engineering begins with a specification of a reference system with elements of the core business that are often sold. The active structure can serve as the basis for communication, coordination and reusing solution knowledge. Figure 3 shows how and where methods of model-based systems engineering can improve the development process of make-to-order products. The applications of the methods are described in the following.

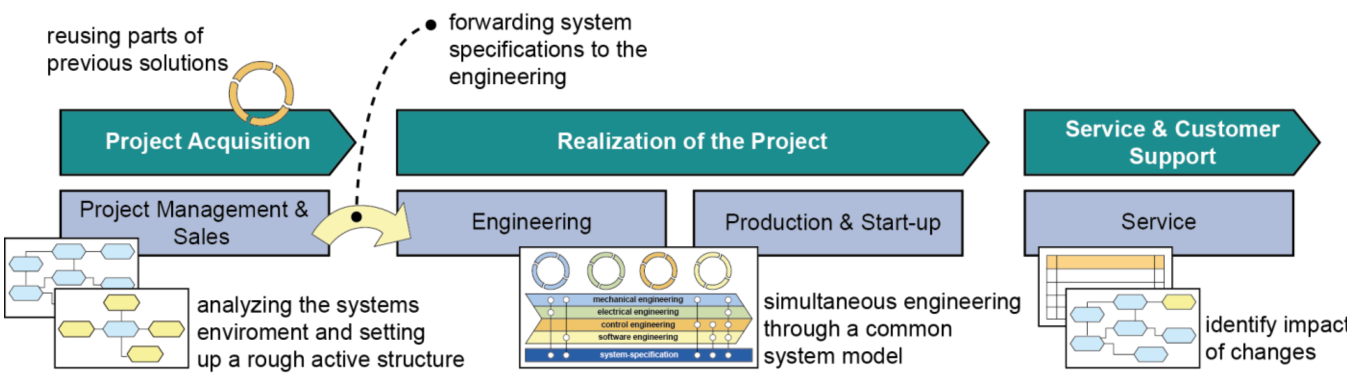


Figure 3 Using model-based systems engineering methods within the development process of engineering-to-order products

The specification of a reference system can be used by the technical sales to explain already realized systems to customers and to show the general structure of the machines. The requirement specification can be supported by an analysis of the environment of the system. Usually new machines are placed at the shop floor besides many other systems. The conditions can vary as well as interconnection to other systems. Discussions with the customer about the environment model can lead to hidden but important influences and interaction between influences. During the requirement specification the technical sales can set up a rough active structure as a basis for further discussions with the customer. At this point functional relations between system elements are more important than the shape of the system that is shown in sketches and drawings. The technical sales can reuse parts from previous projects to set up an active structure with small effort. The detailing of the system model occurs in close cooperation with the customers to meet their requirements.

If the order is placed, the technical sales can forward the system specification to the project management and the different engineering departments. The system model leads to an instant understanding of the requirements as well as the idea and concept developed by the technical sales. In the early stage of the engineering an interdisciplinary team of engineers develop the principle solution and especially the software engineers can contribute their ideas about the machine controlling. The usually mechanical-driven concepts in this field shift to concepts that involve all disciplines. Although, simultaneous engineering is possible since the systems model gives the software engineers in the early stage an idea how the machine controlling needs to be implemented.

Claims for changes usually occur during or after the start-up of the machine on-site at the customer's shop floor. Again the system model helps to understand the claimed changes and, most important, the impact of changes to the whole system. If a part of the system is changed it can affect other parts as well as requirements which can be unobvious and overlooked. If a claim for change occurs, the direct affected system elements within the active structure as well as the affected requirements can be identified. The next step is to analyze the interfaces and interconnection of the system elements and whether further changes are needed. Although it can be traced which requirements are affected by changing system elements. Hence, changes and service operations can be well-coordinated and reduced to a minimum.

6.0 SUMMARY

The present contribution shows that many potentials of using model-based system engineering lie in a better communication which leads to less iteration and changes within the product development. The active structure is a simple way to achieve a common understanding between all involved engineers of the supplier as well as the customer. Although it is easy to implement into the process without the need to introduce complex tools and changing the whole development process. This is a crucial requirement for introducing systems engineering in this sector and the engineering-to-order process successfully.

The aim of our future work will be specific methods for every potential within the process we identified. Although the reusing successfully developed solutions of previous projects will be considered. Even engineering-to-order is characterized through customized solutions, solution patterns are usually reused implicitly based on the experience of the engineers. Standardization of interfaces and a modular design bear high potential in this field.

References

[1] Dumitrescu, R. 2014. Why Intelligent Systems Need MBSE. *Prime Magazine*. 20-12.

[2] Gausemeier, J., Dumitrescu, R., Steffen, D., Czaja, A., Wiederkehr O. and Tschirner, C. 2013. *Systems Engineering in Industrial Practice*. Paderborn.

[3] Giesberts, P. and Tang, L. V. D. Dynamics of the Customer Order Decoupling Point: Impact on Information Systems for Production Control. *Production Planning & Control.* 3(3): 300-313.

[4] International Council on Systems Engineering (INCOSE), Systems Engineering Vision 2020, INCOSE-TP-2004-004-02, Version 2.03, September 2007.

[5] Friedenthal, S., Moore A. and Steiner, R. 2011. *A Practical Guide to Sysml–The Systems Modeling Language*. 2nd Edition. Elsevier, Oxford.

[6] Kaiser, L. 2014. *Rahmenwerkzur Modellierungeinerplausiblen Systemstruktur Mechatronischer Systeme*. Dissertation, University of Paderborn.

[7] Gausemeier, J., Frank, U., Donoth, J. and Kahl, D. 2009. *Specification Technique for the Description of Self-Optimizing Mechatronic Systems*. Springer, London. 20.