TOWARDS MODEL-BASED PROCESS ENGINEERING

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ABSTRACT

The high interaction between process and product models in product development and systems engineering (SE) is common sense. However, most research in the field of model based systems engineering (MBSE) focusses of physical systems (hardware and software). The authors claim that this focus is a main reason for the low acceptance and high effort for implementation of SE and MBSE in industrial practice. Thus, this contribution aims at supporting an integrative analysis and synthesis of process and product models by introducing the concept and framework of Model-based Process Engineering. Based on established research this framework introduces three main systems, namely the system of processes, system of product models, and system of tools to describe complex product development. The main contribution of this work is a preliminary concept to structure and link the systems of processes and product models. Besides form the description of the main relations between the systems an integrated modelling concept to represent links between the process and product model system is proposed.

Keywords: Systems Engineering (SE), Process modelling, Organisation of product development

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1 INTRODUCTION

Product development (PD) is based on and supported by models representing the process and the product. As a result of different activities in the product development process (PDP) a network of models occurs. These models represent the product in different development stages and the views of different engineering domains. Systems engineering (SE) and Model-based Systems Engineering (MBSE) aim at overcoming the barriers between single product models and different engineering domains that often occur in interdisciplinary PD. However, most of SE research focusses on technical (hardware and software) systems (Browning *et al.*, 2006) while only little attention is given to processes and their understanding as emerging systems. The author claims that the missing understanding of interactions between design of processes and design of systems is a major reason for low acceptance and implementation of SE and MBSE in industry, as it is described by (Huldt and Stenius, 2018; Gausemeier *et al.*, 2015; Estefan, 2008; Kasser, 2010). Among others essential challenges reported in these works are the transformation of organisational structures (Huldt and Stenius, 2018) and a lack of methods to support the introduction of SE and MBSE (Gausemeier *et al.*, 2015). To address these challenges, in this contribution the need for an integrated analysis and engineering of process models, defining activities to be performed, product models representing the product, and tools needed to support the PD, is discussed. Guiding hypotheses of this research are: (1) analysis of processes and included activities are essential to derive starting points and requirements to adapt and integrate new product models as a part of implementing MBSE and (2) the impact of SE and MBSE approaches can be evaluated by analysing their effect on the process. Stressing the central importance of process models in product development projects, the author emboss the term Model-Based Process Engineering (MBPE). Following this understanding, model-based approaches have to be applied not only to engineer products but also to engineer processes. Thus, the process is seen as a system that has to be engineered (Browning and Ramasesh, 2007) as a part of MBSE implementation.

1.1 Systems engineering and model-based systems engineering

Systems thinking is essential to handle an increasing amount and diversity of interfaces between different elements of the emerging product during its development. Methodologies from SE and MBSE pick up the basic understanding and elements of established system theory like the hierarchical, functional, and structural system concept (Ropohl, 1974) and are widely used e.g. in aerospace industry (Estefan, 2008). Basic characteristics and objectives of SE are formulated by (Gausemeier *et al.*, 2015) stating *"systems engineering is a consistent, interdisciplinary approach for developing multidisciplinary systems. Not only does it address the system to be developed, but also the associated project"*. This definition expresses the pretence to cover both the view upon the product and the process. In addition to this understanding, MBSE aims for supporting and presenting results of different development activities in one model and thus to shift from heterogeneous, document-based product models to consistent and interlinked product models. Established methodologies of MBSE are characterised by (Estefan, 2008) or (Browning *et al.*, 2006), highlighting that they comprise a process-model and methods and are supported by different tools. Modelling applied in MBSE constitutes the elements language, tool and method. Existing standards, like UML or SysML, define the elements and syntax to be used, while oftentimes tools like Enterprise Architect are applied to build and analyse the models. These tools support the correct application of the language and allow different analysis and views upon the model. The languages applied in MBSE are of generic character, to support representation of different kind of systems. This results in the challenge, to transfer established syntax, elements and tools applied by experts into meta-models using e.g. SysML. Ehrlenspiel and Meerkamm (2013) state that this transfer is often hindering industrial application. Aside from this, several researchers highlight, that there are numerous obstacles to overcome implying that benefits can hardly be quantified and expertise in many industry sectors is missing. Main reason for this is that implementation of SE and MBSE methodologies affect the system of PD deeply. Thus, implementing them in industry involves different stakeholders responsible for particular processes, product models and tools already existing. This situation highlights that not only the development of products is an interdisciplinary task but also implementation of SE and MBSE methodologies requires an integral view upon the (sub-)processes, product models and supporting tools.

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1.2 Contribution and structure of the paper

This research focusses on the introduction and use of SE and MBSE methodologies in industrial practice. It aims for providing a basic comprehension of process and product models as well as supporting tools and the interrelations of these elements within existing PD. This understanding serves as a basis for evaluating required changes and adaptions of existing processes, product models and tools, when introducing SE and MBSE. The proposed concept of MBPE thus shifts the focus form research and engineering addressing product models to the analysis and synthesis of process models, to provide a central theme for integration and modification of product models and tools. The gained insights regarding analysing and synthesing activities, when introducing SE and MBSE, are dedicated to both practitioners and researchers. The contribution provides a common understanding of product development projects, process and product models as well as modelling techniques and integrated product and process models in the next section 2. In section 3, the concept of MBPE is introduced by describing its basic constituents *system of processes*, *system of products* and *system of tools* and their interrelations. In section 4, a preliminary modelling concept is proposed. Section 5 concludes the paper by discussing the results of this contribution and formulating fields of further research

2 BACKGROUND AND LITERATURE

Product development projects (PD projects) are increasingly confronted with the challenge of developing technical products, which are complex systems. The complexity of today's PD projects stems from a rising complexity of the products, containing various interconnected subsystems, whose development requires the involvement of different engineering domains and interlinked development (sub-)processes. With regard to this challenges Chucholowski and Lindemann (2015) state that project management "*is challenged by a high degree of ambiguity and uncertainty both regarding project's objectives [ ] and activities necessary to accomplish the project [ ]*". Moreover, due to increasing product complexity, it is hard to understand all consequences that result from adaptions in project plans. This challenge becomes relevant, when introducing MBSE into existing product development projects, since this affects processes, product models and tools. The following section introduces product development (projects) as complex systems.

2.1 Understanding product development projects as a complex system

Besides technical products in terms of complex systems, PD projects can be understood as complex systems itself. In order to define components and structure of such a system, different concepts are described in literature. With focus on SE, Martin (1996) introduced the PMTE. Following his understanding, essential elements to be consider in SE are *processes* (P), *methods* (M), *tools* (T) and *environment* (E) as well as the capabilities and limitations of *technology*, and knowledge, skills and abilities of the *people* involved (Estefan, 2008). The elements are linked by basic relations, e.g. defining that processes are supported by methods, and processes, methods, tools as well as environment are affected by technology and people. Another relevant model is the ZHOP-model (german: Ziel-, Handlungs-, Objekt-, Prozesssystem) that is based on the ZHO-model (german: Ziel-, Handlungs-, Objektsystem, c.f. (Ropohl, 1974), (Negele *et al*., 1997). Beside processes and products this model introduces the agent and the goal system as two important systems of a project. The agent system includes organisation, relevant technologies, resources, methods as well as tools. While the goal system defines objectives with reference to processes, product and organisation. Based on these works Browning *et al*. (2006) define the organisation and tool system as explicit systems of a project. The five systems of a project are related to each other and are composed of different elements. Thus, each system represents a network structure and architecture. Following the understanding of Browning *et al*. (2006), the *product system* represents the result of the project and consists of desired physical components (hardware and software) and relations between these components differing with regard to type and degree of interactions. The *process systems* consists of a set of related activities, representing the work that needs to be done in order to produce the product system. Moreover, it defines intermediary results achieved during the process. Within the *organization system* individuals, groups, teams, or other organisational units are defined, assigned to do achieve results needed to produce the product system and its subsystems. The *tool system* describes the technologies used by the people to perform their work. Here, a wide range of tools can be addressed including basic tools like sketching boards as well as software tools. As a consequence of the relations between activities (*process system*)

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and the people performing them, interactions between software tools are represented within the tool system. The context of requirements or goals for the project are defined in the *goal system. Like described each of the systems is related to another system, leading to both systems enhancing as well as constraining each other.* Within most projects in industry models exist describing the product, the organisation, and the processes to some extent. On the one hand this is an evident for the basic appropriateness of the described model On the other hand essential deficits with regard to the development and handling of these models in industrial practise can be observed:

- The different models are largely handled as segregate models. Essential interactions and constraints between the introduced systems of a project are neglected.
- Changes made within one of the systems (models) are not translated to the other systems and are thus not verified in the context of the systemic understanding.

With regard to the implementation of SE and MBSE, the discussed understandings of PD projects as complex systems provide an important concept to structure and link different aspects to be considered. To set the focus of MBPE, in this contribution it is emphasised for what purpose and in which way processes, products and tools are used and modelled within existing PD projects. Instead of explicitly considering methods like proposed by Martin (1996), the author uses the product system (product models) to shift the focus to the representation of development results of the emerging product in different PD stages. Moreover, in this contribution the organization system is not considered explicitly. The integration of roles and responsibilities will be part of further research. To gain a deeper understanding of how models are created and used in PD, the following paragraphs outline different models and modelling technologies focussing on processes and products.

2.2 Modelling of processes and products

Distinction between models representing processes and those representing the product is common sense in research on PD and SE. Process models are generated to design, communicate, plan and monitor the process on different levels of abstraction (Eckert *et al.*, 2017). Product models are used to represent the emerging product and its environment with focus on different aspects like requirements, behaviour, structure and parameters. These models are thus used to express, analyse and communicate the design itself (Eckert *et al.*, 2017). However, there is a strong interaction between process and product models, since all development activities like solution generation, evaluation or testing intend to generate or manipulate product models comprising the needed or generated information (Browning *et al.*, 2006).

2.2.1 Process models and modelling techniques

According to Martin (1996), a *"process (P) is a logical sequence of tasks performed to achieve a particular objective"*. Thus, processes and the involving activities are performed to generate intermediary results within the PD. Besides this basic understanding, use and character, process models differ widely (Browning *et al.*, 2006). With regard to the purpose Wynn (2007) defines four categories of process models: *Procedural models* (e.g. VDI 2221 or V-Modell), *analytical models* (e.g. task-DSM (Eppinger *et al.*, 1994) or the Business Process Model and Notation (BPMN)), *abstract models* (e.g. CPM/PDD model of Weber or the FBS model introduced by Gero), and *management science/operations research models* (e.g. Capability Maturity Model for Development). These categories illustrate the different objectives of process modelling and highlights that models of processes are suitable to serve as a basis for analysing and evaluating since they integrate different views upon the PD. Process models and descriptions in industry often interrelate the characters of procedural and analytical process models by defining phases of development (Wynn and Clarkson, 2005). In context of SE, process models that help to manage dependencies among activities and therefore enable coordination, like the V-Model (Kaffenberger *et al.*, 2013) or the iPEM model (Albers and Braun, 2011), are of great relevance. To manage the complexity of real PDP, it is important to structure and aggregate processes of different levels into one model. It enables analysing and defining on various levels of detail and through this, to support different decision-making needs (Estefan, 2008). Moreover, it is essential to address the views of different stakeholders (e.g. management) and provide guidance to the involved engineers and engineering teams.
Consistent integration and linkage of process models is often not given in industrial practice, since processes are modelled graphical using documents and non-standardised syntax. Modern modelling techniques that are based on graphical methods and usage of diagrams, to represent the processes with specific syntax and semantics, are rarely used. A prominent example for formal (graphical) modelling

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languages is the BPMN (OMG, 2011). The syntax and method of BPMN allows to link different process levels and perform various analysis, like stakeholder or critical path analysis. Other process modelling techniques established in industry are Flowchart, Gantt Chart, and UML-diagram used for documentation of intended processes. These modelling techniques are supported by different software solutions and are mainly used to represent processes and activities in the way they should be proceeded. Thus, the main purpose of process models in industry is to represent the intended procedure during PD, by defining responsibilities, deliverables and activities.

2.2.2 Product models and modelling techniques

Product models are representations of the emerging product. They are used to represent, explain and evaluate the current state of development. The models serve as a communication basis and to apply formal methods like variations operations in different development activities. Franke (1976) highlights the understanding of product models by introducing the term p_n-model and defining: *"product-representing models (*$\mathrm{p_n}$*-model) are models of the product to be developed which allow a sufficient and optimal representation of at least those system properties of the product which are treated in the current development stage"*. Following his definition the PD can be described by a network of product models that have to be linked in an appropriate manner. This understanding of product models is mainly focussing synthesising activities. However, there are other purposes to represent the product by models. Eckert *et al*. (2017) classify product models by differing their purpose with regard to the PDP. Thus, the main purposes cover product visualisation, product synthesis, product analysis and evaluation as well as life cycle support. Moreover, product models can be classified according to their abstraction. Albers and Muschik (2010) differ between *content related specification* (system, domain, generic) and *formal specification* (meta-product model, reference product model, product models, and real products). Neither the purpose based nor the abstraction related categorisation do explicitly imply the required interrelation of product models from different involved engineering domains. However, these interrelations are essential to track progress of the PDP and support other activities, like product architecture design or change management. Caused by the wide range of codes and mediums used to model the emerging product, modelling techniques for product models differ widely. Aside from different standards to represent for instance requirements or functions in textual and graphical ways, in practice there are countless symbols and forms (syntax) to represent information about products in documents. This often hinders to identify and illustrate the needed interrelations between product models both within a model and across domains.

2.2.3 Integration of process and product model information

Although there are great differences in what process and product models represent, in practice there is a need to integrated information of both model types. This is highlighted by the survey of Sharon *et al.* (2011) defining fourteen management factors of SE mentioned by practitioner to allocate these to the project and product domain. The necessity to integrate both views is thus immanent to facilitate risk or change management and eases communication. Eckert *et al*. (2017) argue that models integrating process and product information are useful to define and handle trade-offs between design characteristics and process performance. Sharon *et al*. (2009) emphasise that models of the process should support the iterative character of PD based on derivations, refinements and simulations of the models representing the product and should maintain traceability and coherence between the product model and the project plan at all levels and in both directions. For integrating information of process and product models, different concepts exist c.f. (Eckert *et al*., 2017; Wynn and Clarkson, 2018). Multiple-Domain Matrices (MDM) for instance allow to link tasks of the process to components and teams (Danilovic and Browning, 2007) and thus to route coordination activities and communication in cases of design changes and iterations. Graphical notations like the Object-Process Methodology (OPM) combine the representation of processes and objects by formal notation or equivalent formally structured sentences (Dori, 2002). The OPM further helps to structure models by representing a hierarchically organised set of object-process diagrams (OPDs) including both processes and their related objects (ISO/PAS19450, 2015). Sharon *et al*. (2013) introduce a modelling concept based on OPM that supports planning and controlling development projects, by linking project tasks (represented as processes) to the required resources and the hierarchy of deliverables (represented as objects). Sharon and Dori (2015) further propose a project-product model-based approach to plan breaking down structures helping to avoid mismatches and inconsistencies between the models and documents used to manage a project.

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Comparable to OPM, linking of activities within process and product models can be realised by combining BPMN artefacts and SysML-models, see section 4.
The models and modelling techniques introduced to represent processes and products represent concepts established in research as well as standards for modelling. However, there are hardly any applications in industry particularly with focus on the integration of process and product information. This hinders effective implementations of SE and MBSE. Based on the disclosed necessity to integrate information of both models for the planning and coordination of PD, in the following section the concept and framework of Model-Based Process Engineering (MBPE) is introduced. The framework includes the fundamental concept of system thinking and modelling to analyse and synthesise the systems of process and product models as well as includes the supporting tools considering the essential interrelations.

3 FRAMEWORK OF MODEL-BASED PROCESS ENGINEERING

The concept and framework of MBPE aims at providing a structured basis to implement methodologies of SE and MBSE into running PD in industry as well as to support coordination of interdisciplinary work needed for successful implementation. It is based on the established interaction between the the systems in product development projects, see Section 2.2. MBPE understands PDP as a system constituted by the subsystems of *processes*, *product models,* and *tools*.

3.1 Objectives and hypotheses of the model-based process engineering concept

Objective of the MBPE concept is to represent and structure interactions between the systems of *processes*, *product models* and *tools* on different levels of aggregation, when planning and implementing SE and MBSE in existing product development surroundings. The concept can be applied to analyse existing systems of PD in practice as well as to adapt and substitute single sub-processes and activities or partial models of the product, when introducing SE and MBSE. Relevance and objective of the concept are highlighted by the following observations in industry:

- Implementation of SE and MBSE in industry constitutes a transformation process involving different stakeholders and adaptions of processes, product models and tools. Thus, it is essential to analyse the existing structure of process and product models and their interactions.
- Process models serve to integrate the view of different engineering domains and management perspectives, when planning and coordinating design activities. They serve to identify shortcomings of existing product models and tools (analysis view). Furthermore, potentials of adapted and new product models and tools can be evaluated using process models (synthesis view).

Since the focus of the MBPE concept is to support the implementation of SE and MBSE into industry, it highlights the importance of the processes as a means to identify deficits in existing PDP.

3.2 The model-based process engineering framework

The MBPE framework contains three systems and their relations of different levels of aggregation (process and product models), c.f. Fig. 1. Each of the elements is seen as a system implying a hierarchy of processes and product models as well as a structure formed by the relations between single product models or tools.

3.2.1 System of processes

The *system of processes* represents processes and activities on different levels of abstraction, determining the sequence of sub-processes and dedicated stakeholders as well as points of decisions (events). Thus, it has the character of an analytical process model (Wynn and Clarkson, 2018) and involves the management oriented view upon the PDP by defining for instance points of time to deliver specific results (over all process view, *marco level process*). Constituents of the system of processes are activities, events, stakeholders and information flows. These elements are linked by interactions and logical relations, e.g. activity requires successful event. Thus, the system of processes serves as orientation for the different involved engineering domains (*meso level process*, c.f. Fig. 1). Moreover, it represents the logic of PD by defining what to do on a more detailed level for each engineering domain (*micro level process*, c.f. Fig. 1). The single process models within the system of processes are structured hierarchically by decomposing the processes of higher levels, like decomposing the process determination of requirements into the sequence of activities: gathering requirements, documenting requirements and harmonising as well as evaluating requirements.

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3.2.2 System of product models

The *system of product models* comprises all models used to represent the emerging product in different development stages with regard to different views and engineering domains. Therefore, it aggregates different partial models focussing on requirements, behaviour, structure and parameters with regard to the different engineering domains creating and using these models. At the same time the *system of product models* is used to represent relations between the single partial models and thus illustrates the network of product models used for PD. The hierarchical structure is based on the differentiation between *product models* (directly applied models), *domain models* (linking partial models of different engineering domains) and *meta models* (aggregating the models of different product development projects). The basic compositions and interrelations of the partial models follow the currently applied product development methods and their logic of what to model and how to use different model instances and thus clarifies relationships between the models (Eckert *et al.*, 2017). It is also considered, if and how information of different models are aggregated by superior models (domain and meta models) and which structural characteristics of the single models are used to link these.

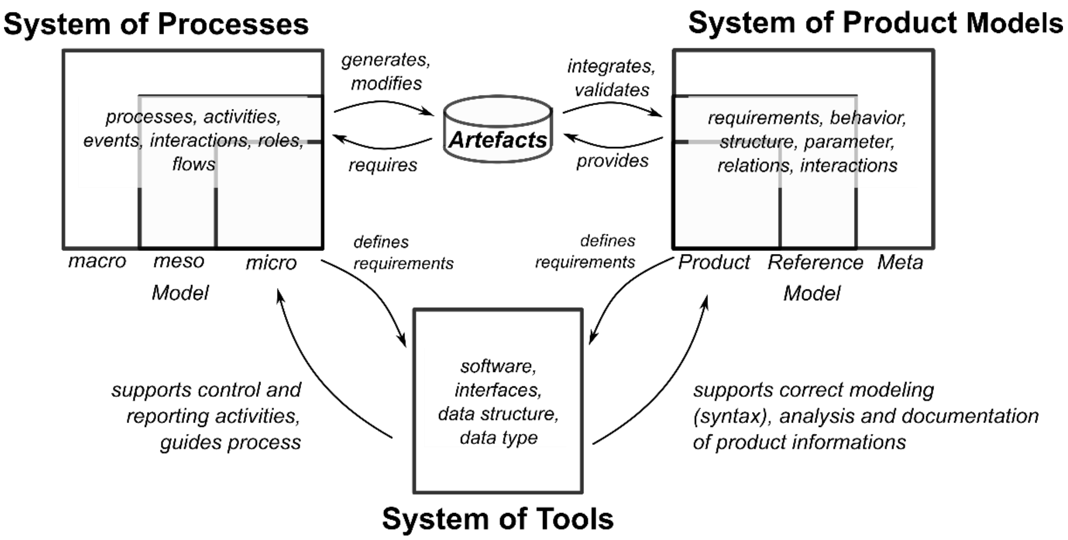

Figure 1: Systems and their main interrelations within the model-based process engineering framework (MBPE)

3.2.3 System of tools

The third system within the MBPE framework is the *system of tools*. According to Estefan (2008) tools are instruments that enhance the efficiency of task when applied to a particular activity. In the context of MBPE tools are seen as the means to generate (e.g. for specific views), manipulate and hold product and process models. This understanding implies for instance tools for text processing or spreadsheet programs as well as complex tools like PDM or PLM software. Thus, the *system of tools* represents the variety of tools applied within the PDP as well as their required compatibility caused by the interaction between activities (*system of processes*). It is emphasised as a separate subsystem of the framework, to highlight the supportive role the tools should have in PD. The purpose of this system therefore is, to represent functionalities, supportive languages, data formats and data types of the used tools as well as the layout plan of software systems installed within an enterprise. This is of great relevance, when planning software system architecture in big companies or networks of enterprises. On the one hand, the system of tool can be applied for analysis purposes, for instance when deciding which tools to deactivate or which and how to replace software systems. On the other hand, based on the system of product models and processes, specific requirements can be derived to choose suitable tools or develop and adapt the data model of tools. Thus, the relations between the systems of processes and product models help to span the bridge between the technical views of the involved engineering domains and the stakeholders responsible for the tools.

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3.2.4 Interrelations between the systems of model-based process engineering

Between the introduced systems of the MBPE framework there are strong interrelations, see Figure 1. The type of interrelation mainly depends on the case the framework is used for, since most of the relations are directional. In case of analysis starting from the *system of processes*, this system specifies the purpose of the product models based on the definition of a particular activity or stakeholder and the information needed, as well as the different product models that have to be applied. The *system of processes* and the *system of product models* are connected through artefacts. On the one hand, these artefacts are results of activities which generate or modify them. On the other hand, artefacts are needed to perform an activity. From the perspective of the *system of product models* the artefacts are understood as *information elements* that are integrated and validated by the product model. Moreover, the view out of the *system of processes* into the *system of product models* defines which level of aggregation of models is needed depending on the task to be fulfilled. For instance, when evaluating the crash properties of a car or testing a single software component, different information (different properties and characteristics) about the product system and sub-systems are required. The other way around the *system of product models* specifies the sequence of activities to be carried out within one domain or across domains to generate the information. The interrelation between the *system of processes* and the *system of tools* is given by activities and stakeholders within the processes. Thus, the *system of processes* also defines tools used to support single activities. The *system of tools* defines whether activities are needed to transform or modify artefacts in order to prepare these e.g. for following activities. These activities for instance indicate missing compatibility of the applied tools. Interrelations between the *system of product models* and the *system of tools* are representing the requirements resulting from the applied product models e.g. with regard to data structure and analytical functionalities of particular tools. The tools and supported languages mainly influence the possibilities of integrating different product models or the necessity of introducing superior meta-models using domain spanning languages.

Based on the description of the framework for MBPE, in the following section a modelling concept is introduced, to support explanation of the introduced elements and interrelations of the *system of processes* and the *system of product models*.

4 PRELIMINARY MODELLING CONCEPT

The objective of the proposed preliminary modelling concept is formalize the linkage of processes, sub-processes and process activities with elements of the *system of product models*. The *system of processes* is modelled using BPMN. Process modelling starts from the macro level and is detailed into sub-processes (meso level). At the lowest level (micro level) single activities to be performed by the process executing participants are defined. Figure 2 illustrates modelling concept containing the different levels of the *system of processes* for a milestone-based PDP (marco level) and the requirements determination sub-process (meso level). The example illustrates that each process has a pool that represents the stakeholder (process owner). The pools include one or more lanes corresponding to one process participant. Within the lanes, the activities and events of the process are arranged. In case of the BPMN, a process is always triggered with at least one start event and ends with at least one end event. Figure 2 gives an example of the integrated modelling of the *system of processes* and the *system of product models*. To link the system artefacts of a product model that are used or required by process activities, these are related to the elements of the process model. The relations between process activities and elements of the *product system model* are unidirectional modelled as input or output. If a product model used in the process is not (yet) detailed in the *system of product model*, BPMN elements of type << Data Object >> or << Data Store >> are initially created as wildcards. These are later replaced, when the *system of product models* is extended by the corresponding product models. The *system of product models* itself is subdivided into several product models, each representing certain aspects of the product to be developed. For each of these product models, the internal structure and content is defined. Thus, there is a partial model, in which product requirements are documented. Other partial models represent, for example, a generic product structure or domain-specific views. Very often the elements of the different partial models influence each other or are in some way related (e.g. compositions within the product structure) To document these relations, the elements can be linked to each other and the interdependencies can be further described. For example, the requirements are linked to the elements of a generic product structure, to document which requirements are to be taken into account for specifying certain elements of the product structure.

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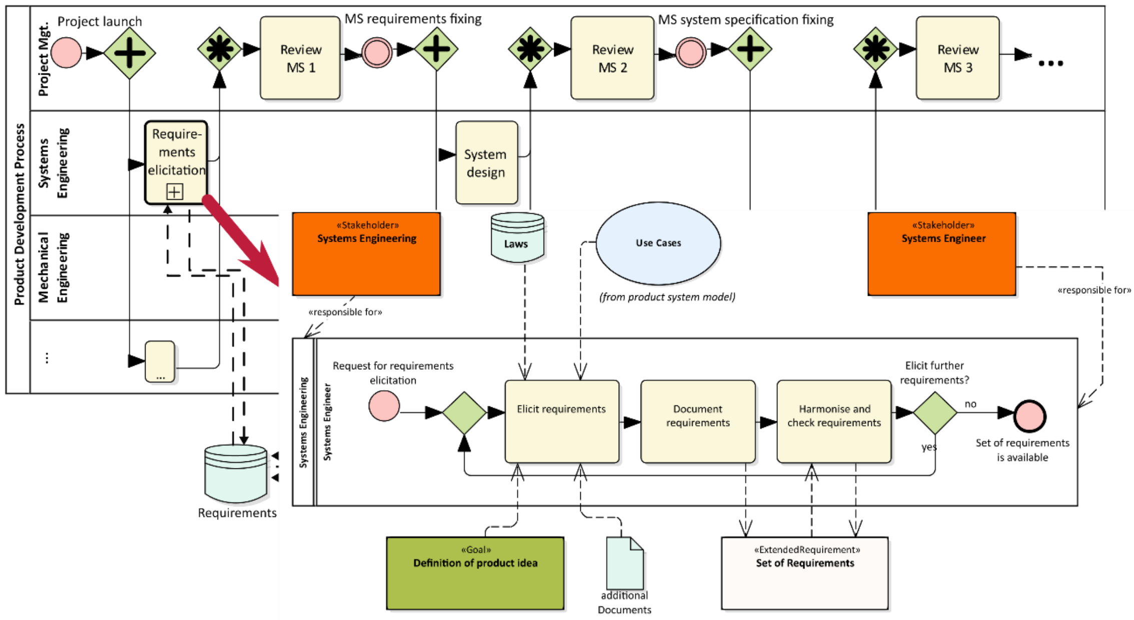

Figure 2: Milestone-based development process as superordinate process containing the detailed sub-process for requirement determination (top). Integrated modelling of the system of product models involving a set of requirements as a model on product level (bottom)

To create the integrated model a specific System and Process Engineering Profile is used (Huth *et al.*, 2018). The profile defines the types of elements available for modelling the partial models. The profile builds on the established modelling languages UML, SysML and BPMN and extends or modifies their elements with new stereotypes using the UMLs profiling mechanism, so that there are specialized elements to be used for the MBPE approach available.

5 CONCLUSION AND FUTURE WORK

The high relevance of interactions between process and product models in product development (PD) and systems engineering (SE) is common sense. However, most research in the field of model based systems engineering (MBSE) focusses on physical systems (hardware and software). The authors claim, that this focus is a main reason for the low acceptance and high effort required for implementation of SE and MBSE in industrial practice. Thus, this contribution aims for supporting an integrative analysis and synthesis of process and product models by introducing the concept and framework of Model-based Process Engineering (MBPE). Based on established research, this framework introduces three main systems, namely the *system of processes*, *system of product models*, and *system of tools* to describe complex PD. The main contribution of this work is a preliminary concept to structure and link the *systems of processes* and *product models*. Besides the description of the main relations between the systems, an integrated modelling concept for elaborating links between the process and product model system is proposed. Future work will focus on the refinement of the structures and relations between the introduced systems of the MBPE framework as well as the modelling concept. Furthermore, a graph-base concept will be elaborated, to support the representations and analysis of interactions between the single systems. Therefore, further classification and formalisation of the elements and relations in and between the *systems of processes*, *product models* and *tools* is needed. Applicability and advantages of the MBPE framework and the graph-based concept will be evaluated using examples of processes and product models from automotive industry. Moreover, work is planned to integrate the organizational view in more detail into the MBPE framework.

REFERENCES

Albers, A. and Braun, A.C. (2011), “A generalised framework to compass and to support complex product engineering processes External Link”, *Int. Journal of Product Development*, Vol. 15 No. 1-3, pp. 6–25. http://doi.org/10.1504/IJPD.2011.043659.

https://doi.org/10.1017/dsi.2019.381 Published online by Cambridge University Press

Albers, A. and Muschik, S. (2010), “Development of Systems of Objectives in Early Activities of Product Development Processes”, *Proceedings of the Eighth International Symposium on Tools and Methods of Competitive Engineering (TMCE 2010)*.
Browning, T.R., Fricke, E. and Negele, H. (2006), “Key Concepts in Modeling Product Development Processes”, *Systems Engineering*, Vol. 9 No. 2, pp. 104–128. http://doi.org/10.1002/sys.20047.
Browning, T.R. and Ramasesh, R.V. (2007), “A survey of activity network-based process models for managing product development projects”, *Production and Operations Management*, Vol. 16 No. 2, pp. 217–240. http://doi.org/10.1111/j.1937-5956.2007.tb00177.x.
Chucholowski, N. and Lindemann, U. (2015), “An Initial Metamodel to Evaluate Potentials for Graphbased Analyses of Product Development Projects”, *Proceedings of the 17the International Dependency and Structure Modelling Conference, DSM 2015*.
Danilovic, M. and Browning, T.R. (2007), “Managing complex product development projects with design structure matrices and domain mapping matrices”“, *International Journal of Project Management*, Vol. 25 No. 3, pp. 300–314. http://doi.org/10.1016/j.ijproman.2006.11.003.
Dori, D. (2002), *Object-Process Methodology: a holistic systems paradigm*, Springer-Verlag, Berlin, Heidelberg.
Eckert, C.M., Wynn, D.C., Maier, J.F., Albers, A., Bursac, N., Xin Chen, H.L., Clarkson, P.J., Gericke, K., Gladysz, B. and Shapiro, D. (2017), “On the integration of product and process models in engineering design”, *Design Science*, Vol. 3 No. 3), http://doi.org/10.1017/dsj.2017.2.
Ehrlenspiel, K. and Meerkamm, H. (Eds.) (2013), *Integrierte Produktentwicklung: Denkabläufe, Methoden-einsatz, Zusammenarbeit, Hanser eLibrary, 5,* Auflage, Hanser, München.
Estefan, J.A. (2008), *Survey of Model-Based Systems Engineering (MBSE) Methodologies*, RevB, California, USA.
Franke, H.J. (1976), *Untersuchungen zur Algorithmisierbarkeit des Konstruktionsprozesses*, *PhD-Thesis*, TU Braunschweig.
Gausemeier, J., Dumitrescu, R., Steffen, D., Czaja, A., Wiederkehr, O. and Tschirner, C. (2015), *Systems Engineering in Industrial Practice*, Paderborn, Germany.
Huth, T., Inkermann, D., Wilms, R. and Vietor, T. (2018), “Towards Model-based Process Engineering An approach to integrated product system and process modelling”, *Proceedings of EMEASEC 2018 / TdSE 2018*, Berlin.
Huldt, T. and Stenius, I. (2018), “State-of-practice survey of model-based systems engineering”, *Systems Engineering*, Vol. 22 No. 2, pp. 134–145. http://doi.org/10.1002/sys.21466.
ISO/PAS19450 (2015), *Automation systems and integration-object process methodology*, International Organization for Standardization.
Kaffenberger, R., Schulze, S.O. and Weber, H. (2013), *INCOSE Systems Engineering Handbook*, Carl Hanser Verlag, München.
Kasser, J. (2010), “Seven systems engineering myths and the corresponding realities”, *Proceedings of the Systems Engineering Test and Evaluation Conference*, Adelaide, Australia, May 3, 2010, pp. 1–13.
Martin, J.N. (1996), *Systems Engineering Guidebook: A Process for Developing Systems and Products*, CRC Press, Inc., Boca Raton, FL.
Negele, H., Fricke, E. and Igenbergs, E. (1997), “ZOPH—a systemic approach to the modeling of product development systems”, *Proceedings of 7th Annual Symposium of INCOSE*, Los Angeles, pp. 773–780.
OMG (2011), *Business Process Model and Notation™ (BPMN™) Version 2.0*. [online] Available at: http://www.omg.org/spec/BPMN/2.0/
Ropohl, G. (1974), *Systemtechnik - Grundlagen und Anwendung*, Hanser, München.
Sharon, A., de Weck, O.L. and Dori, D. (2011), “Project Management vs. Systems Engineering Management: A Practitioners’ View on Integrating the Project and Product Domains”, *Systems Engineering*, Vol. 14 No. 4, pp. 427–440. http://doi.org/10.1002/sys.20187.
Sharon, A., de Weck, O.L. and Dori, D. (2009), “Is There a Complete Project Plan? A Model-Based Project Planning Approach”, *Proceedings of Annual INCOSE International Symposium*, Vol. 2009, pp. 96–109. http://doi.org/10.1002/j.2334-5837.2009.tb00940.x.
Sharon, A., de Weck, O.L. and Dori, D. (2013), “Improving project-product lifecycle management with model-based design structure matrix: A joint project management and systems engineering approach”, *Systems Engineering*, Vol. 16 No. 4, pp. 413–426. http://doi.org/10.1002/sys.21240.
Sharon, A. and Dori, D. (2015), “A Project–Product Model–Based Approach to Planning Work Breakdown Structures of Complex System Projects”, *IEEE Systems Journal*, Vol. 9 No. 2, pp. 366–376. http://doi.org/10.1109/JSYST.2013.2297491.
Wynn, D.C. (2007), *Model-based approaches to support process improvement in complex product development*, *Phd Thesis*, University of Cambridge.
Wynn, D.C. and Clarkson, P.J. (2005), “*Models of Designing*”, In: P.J. Clarkson and C. Eckert, (Ed.), *Design process improvement: A review of current practice*, Springer London. http://doi.org/10.1007/978-1-84628-061-0_2.
Wynn, D.C. and Clarkson, P.J. (2018), “Process models in design and development”, *Research in Engineering Design*, Vol. 29 No. 2, pp. 161–202. http://doi.org/10.1007/s00163-017-0262-7.

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