View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by KITopen

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 50 (2016) 100 – 105

www.elsevier.com/locate/procedia

26th CIRP Design Conference

iPeM – integrated Product engineering Model in context of Product Generation Engineering

Albert Albers, Nicolas Reiss*, Nikola Bursac, Thilo Richter

Karlsruhe Institute of Technology (KIT) - IPEK Institute of Product Engineering, Kaiserstr. 10, 76131 Karlsruhe, Germany

* Corresponding author. Tel.: +49 721 608-45985; fax: +49 721 608-46051. *E-mail address:* Nicolas.Reiss@kit.edu

Abstract

Divergent customer requirements demand a product portfolio, which needs to be strategically coordinated. Furthermore, products are developed in generations. Thus, a coordination of the different generations is needed. For a successful support, process models can be used. The integrated-Product-engineering-Model (iPeM) is an integrated approach, which aims to fill in the gap between process management and engineering design. Building on an empirical study of the use of the iPeM in the last 10 years, the iPeM has been modified. This includes an adaption of the activities and an extension from the second to the third dimension. There are four different layers added: product generations, strategy as well as production- and validation system. The adapted model allows inductively refining the theory and deductively creating of boundary conditions for the research on product development.

© 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference

Keywords: Product Generation Engineering, Process Modells, Design Process Management and Organization,

1. Motivation

About 10 years ago the integrated Product engineering Model (iPeM) [1] was developed and since than consistently applied in various projects and more than 100 publications. It forms the basis for research on methods and processes of the Karlsruhe school on product development (KaSPro) [2]. It has proved its usefulness and experienced small adjustments in recent years [3]. However, recent approaches of product generation engineering require a higher adjustment to map different product generations within the model. Moreover, the work of GAUSEMEIER et al. [4] shows the necessity of the integration of strategic product planning into product development. Therefore, strategy should be considered in a holistic product development model. Based on the findings of recent years and the discussions in the context of the current revision of the VDI guideline 2221 [5], where the authors of this contribution are involved, a fundamental improvement of the iPeM now is carried out.

2. State of the Art

For the further development of the iPeM first the current state of the art on the product generation engineering, product models and the iPeM are presented.

2.1. Product generation engineering

A broad empirical study across various industrial sectors and company sizes showed that over 80% of products are developed in generations [6]. Regarding a new product the degree of novelty should be identified by subsystems that have been newly developed and by subsystems that are carried over in order to reduce cost and risk [7]. Therefore, the new product generation is based on one or more existing products defining the main structure of the new product. These products are called "reference products" and can be e.g. precursory products or products of competitors [8]. Examples for product generation engineering shown in Fig. 1 are the Porsche 911 and printing machines by Heidelberger Druckmaschinen AG.

2212-8271 © 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference
doi:10.1016/j.procir.2016.04.168

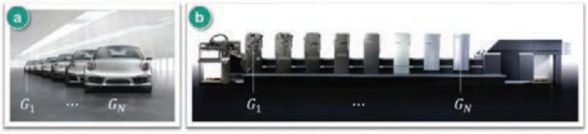

Figure 1: Product generation engineering from G_1 to G_N using the example of products from Porsche (a) and Heidelberger-Druck (b) (according to [9])

2.2. Process Models

There is a number of process modelling approaches in industrial practice. On the one hand, process models serve as a communication basis for the development of new products and on the other hand, to establish an ontology for research on product development processes (PDP). Thereby, the focus of each model is on different aspects [10]. According to WYNN and CLARKSON [11], a broad range of product development process models can be classified. They distinguish between stage- and activity-based models, between problem- and solution-oriented strategies, and abstract, analytical and procedural approaches. Modern machines and vehicles are mechatronic products with complicated structures that are linking mechanical, electro technical and information technical solutions in order to enable new functions [12]. This contains an increased complexity of product development processes, which originates from the direct and indirect interaction of different solutions. Restrictions of the general enterprise strategy must be considered by new development or advancement of products [13]. Boundary conditions limit the scope of action and complicate trough that the achievement of objectives. Product development processes can be seen from an economic view, as well as a technical-methodical perspective [14]. Research on development approaches is an important subject for many decades. The contingency and diversity of product development can be supported with a holistic philosophy of development, based on Systems Engineering [15]. In particular PAHL and BEITZ [13] have delivered basic contributions in the field of process research. On the base of these approaches, different directives, which should help the practical person, were derived. Now, however, it appears that these attempts are not sufficient to illustrate the dynamic and the interconnections of modern PDP. Thus, a new generation of researchers work for about 15 years to address these challenges. In the research group around LINDEMANN the Munich Procedural Model was developed which supports the flexibility of actions and aims a pragmatic use [16]. GAUSEMEIER and his group also investigate the process of the product origin in the three-cycle model [4]. It illustrates the aspects of product planning, product development and production system development in interdependent cycles. Other established modelling approaches such as „VDI 2221 - methodology for developing and designing technical systems and products" [17], CMMI (Capability Maturity Model Integration) [18], as well as the V-Model VDI 2206 [19] or stage gate processes [20] do not cope with the mentioned trends. Mainly in process modelling a complete integration of Strategies and product generation management into PDP is not sufficiently considered. The IPEK research group around ALBERS works on new attempts of modelling product development processes taking into account the dynamism and the uniqueness of product development processes. In this context the integrated Product engineering Model (iPeM) has originated [1].

2.3. The integrated Product engineering Model (iPeM)

"Product development is an endeavour process of multi-functional activities done between defining a technology or market opportunity and starting production" [21]. Furthermore, product engineering includes the development of the production system and the production process as well as all other activities throughout the product lifecycle such as sales or decommission that have a big impact on product development [22]. Some key factors for successful products are: create customer value, short development cycles and a competitive market price [23]. An effective process can support the attainment of these criteria.
Most modelling approaches focus only on certain points, but do not consider an interaction between activities, requirements, results and methods. The integrated Product engineering Model (iPeM) is an integrated approach which aims to fill in the gap between process management and engineering design (Figure 2) [24].

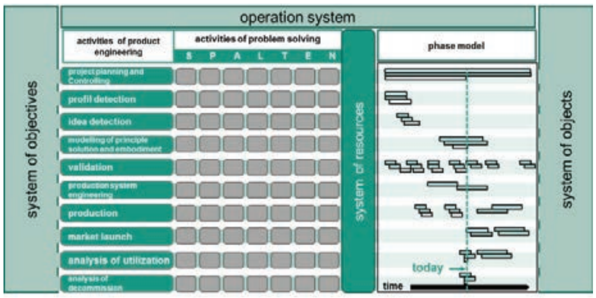

Figure 2: The integrated Product engineering Model (iPeM)

The iPeM is a generic meta-model, which contains the relevant elements to derive situation-specific PDP models. The iPeM is based on the system triple of product engineering: it describes product engineering as a continuous interaction of the system of objectives, the system of objects and the operation system [25]. Based on the system theory, the aim is to transform a system of objectives, into the system of objects [26]. The system of objectives comprises all explicit targets of a product that is going to be developed, including their dependencies and boundary conditions. At the end of the development process, the system of objects corresponds to the product. The operation system does this conversion. The operation system is a socio-technical system, which is composed of structured activities, methods and processes as well as needed resources for the realization, e.g. staff and budget.
The activities of the iPeM are divided into macro and micro activities [22]. Micro activities appear iteratively in technical problem solving, whereas macro activities provide areas of product engineering. The activities of product engineering represent the relevant fields of action of the product developers. This means that these fields represent search regions, which can supply the necessary information. The macro activities according to [26] are listed below:
Project planning and controlling: Sum of the activities at the beginning of a PDP - including planning of the initial system

of objectives and operation system – as well as their continuous controlling and regulation. **Profile detection:** Identification of customer use and supplier's use as well as solution-neutral characterisation of the qualities of a future product. **Idea detection:** finding solutions for the holistic treatment of the profile. **Modelling of principle solution and embodiment:** detailed elaboration of the product idea taking into account technical and economic aspects. Development of the physical connection of function and embodiment. **Validation:** continuous comparison of objects and their objectives. **Production system engineering:** Activities that are necessary to be able to produce the product. **Production:** Manufacturing activities for the realisation of the product. **Market launch:** Activities, which serve for the marketing of the product. They enclose the implementing of a distribution network work, as well as the definition of a marketing strategy. **Analysis of Utilization:** Anticipation of the future user's behaviour and identification of improvement potentials with existing products. **Analysis of Decommission:** Anticipation of the possibilities of recycling after the end of the product life cycle.
In the meta-model iPeM, SPALTEN problem-solving process is used to specify the micro activities [27]. SPALTEN is a German acronym which means "to split" and it stands for a cycle of problem-solving activities in a specific structure or sequence; situation analysis (S), problem containment (P), detection of alternative solutions (A), selection of solutions (L), analysis of consequences (T), deciding and implementing (E) and recapitulation and learning (N). A situation in the PDP is understood therefore as a combination from Micro-and Macroactivity. These are ordered chronologically in the phase model.

3. Aim of research and methodology

Although most products are developed in generations, the current product development models focus on the development of only one product. The aim of this paper is therefore to further develop the existing iPeM. Therefore, an empirical study of the use of the iPeM in the last 10 years was accomplished. Building on these results and a literature research the iPeM has been modified (figure 3).

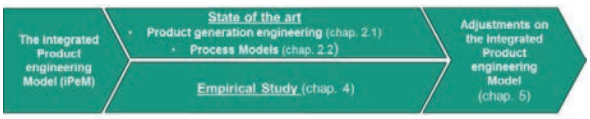

Figure 3: Development process of the new iPeM

For the survey it is relevant to involve experts who have already worked on product development models during their studies (about 600) or their doctorate at the institute (about 100) intensively. For this quantitative survey, designed with the online survey tool LimeSurvey, over 3 weeks, 636 alumni of the institute were contacted by email. Of which N=108 alumni have participated in the survey. This resulted in a response rate of 17%. The sampling process can be regarded as random sampling, since the researchers had no control over whether or not the members of the population participated in the survey. Based on Cochran's formula this means a sample interval width of +/- 6.5%, which states that with 95% confidence any other sample of the population would vary with a maximum of +/- 6.5 % in answer distribution; the survey data is thus of good quality and is regarded as representative for the population. Study participants work in various industries and positions.

4. Empirical study of the use of iPeM in the last 10 years

The underlying idea of this paper is the empirical study of application of process models in the product generation engineering processes. The questions concern three central aspects: knowledge about process models, demands on process models, and the satisfaction of the requirements. Additionally, various firm characteristics were subject to the inquiry. The survey provides answers from engineers in companies of miscellaneous size and branches.
In the study it was investigated how process models, used by developers, are rated regarding their quantitative and qualitative applications. Figure 4 describes the answers to the question which of the mentioned process models are particular known by the respondents.

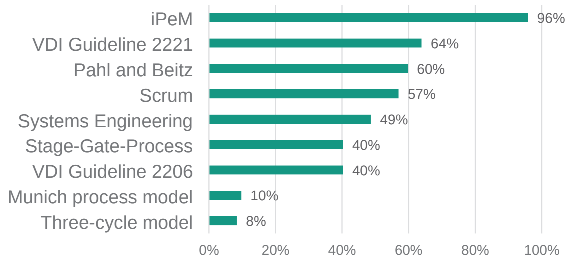

Figure 4: Reputation of the mentioned process models

To be able to analyze the listed approaches concerning their performance, principal purposes of the used process models are introduced. In the survey the participants prioritise the different aims of process models (rank 1 - most important aim to 5 - least important aim). The results are shown in figure 5. For the participants planning of process is the most important aim. Whereas the support with the selection of methods and process controlling are estimated as less relevant.

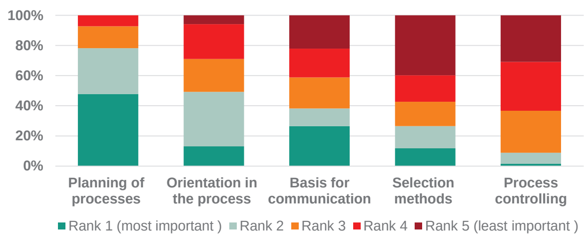

Figure 5: aims of process models

In the next step it was investigated, how the process models support these aims. The different models were rated on a scale of 0 (low) to 5 (high). In figure 6 it can be seen that the models have different strengths and weaknesses. While Scrum indicates, for example, big strengths in the planning of processes, stage gate models show big benefit in controlling of processes.

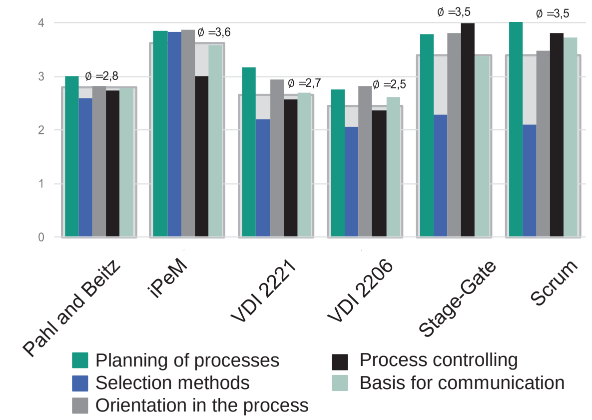

Figure 6: Reputation of the mentioned process models regarding different aims

In addition, the average value was formed which statements about the whole performance admits. Among the 108 participants the integrated Product engineering Model (iPeM) was valued best of all with a value of ∅3.6, closely followed by Scrum and stage gate models with ∅3.5 each.

Demands on future process models were questioned, in order to allow an advancement of the model. Figure 7 visualises the evaluation of the questioning in the form of Whisker-box-Plot charts.

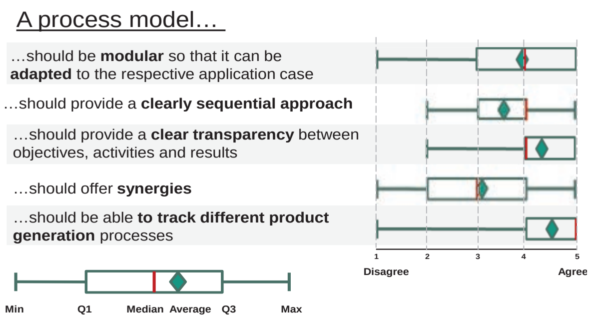

Figure 7: Demands on future process models

Because of the survey results, an adaptive architecture, the creation of transparency and the integration of different product generations should be an aim of process research.

5. Adjustments on the integrated Product engineering Model (iPeM) in context of the product generation engineering

To satisfy the identified demands on a successful process model, the iPeM has been expanded. The logic structure of the iPeM has not been changed fundamentally. The expansion, specifically, was implemented as follows: First, the activities of the operation system were adapted. Secondly, this new developed model was projected to multiple layers. Thereby, different areas of a company or a project can be represented in each layer (figure 8).

The adaption of the activities includes a quantitative expansion as well as the restructuration of already existing activities. The already existing activities "activities of product engineering" (first activity-cluster in figure 8) are complemented by the cluster "basic activities" (second activity-cluster in figure 8). Each of these clusters includes individual activities. The following section describes the two different clusters of activities and their individual components. The description of these is being limited to the added activities.

Cluster "product engineering activities": These are the core activities of product engineering. They can be applied on any development process. In this cluster only one activity has been added. "**Built up prototype":** This activity is necessary to perform the activity "validate and verify". It is carried out at different maturity levels and can contain physical prototypes as well as virtual ones.

Cluster "basic activities": They are conducted parallel to all other activities and in a regularly recurrent mode, to support, improve and secure the product development process. It consists of the new activities: "manage knowledge" and "manage modifications" as well as the existing activities "manage projects" and "validate and verify". **"Manage knowledge":** Gaining an overview of internal and external data, information and capabilities. Further elements are identification, acquisition and development of knowledge as well as distribution, use and maintenance of this knowledge (e.g. [28]). **"Manage changes":** Including the coordination of technical, economic and social changes. The inherent elements are: the examination of early detection of errors and the potential as well as the implementation of respective measures. For example, this applies to the response to a new set-actual situation, which might set forth a design optimization or a new customer requirement. The SPALTEN problem-solving process also structures these activities. The "basic activities" cannot exist on its own, but support other product development activities, e.g., to validate the idea of a new product.

The second significant adaption, is a representation of different approaches of product engineering and the product generation engineering in the model. Any of these approaches (product, strategy, production system, validation system) or any single product generation forms an individual layer. The following section describes the multiple layers of the iPeM. The different layers are as followed the product generations itself, the company's strategy, the production system and the validation system. Each layer consists of the exact same structure and the activities can be applied to each of these layers and modified according to the specific view. This structure allows a focused approach to the respective system in development with a simultaneous integration of the other layers.

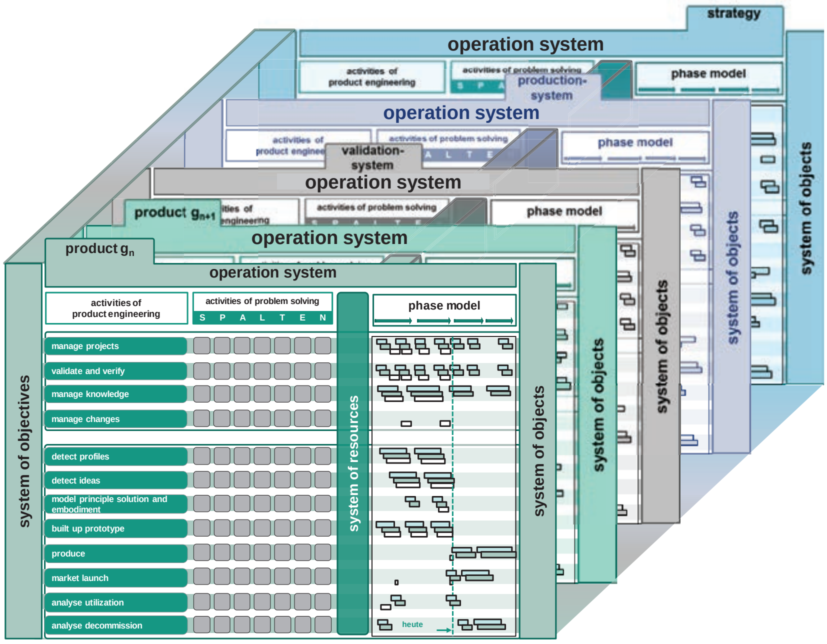

Figure 8: The integrated Product engineering Model (iPeM) in context of the product generation engineering

Layer – "product": The first layer describes the development of the product itself. As products are developed in generations, it is possible to add one layer for each of these individual generations. In this manner, the interrelations of different generations can be mapped (e.g.: an engine is developed for a vehicle generation and should be carried over to the next generation). Furthermore, the resources can be scheduled over several projects. The (temporal) dependencies of the phases of product life cycle and the different product generations can be processed in the phase model.

Layer – "validation system": In this layer elements are developed, which enable the validation of further products. Thus, this layer describes a particular product development process, which is characterized by the already described activities. E.g. a test bench has to be planned, designed and validated as well. This layer should not be distinguished with the basic activity "validate and verify" but provides the essential products as a result.

Layer – "production system": They involve all operations which are relevant to enable an effective and efficient production: from establishing the production system to the production itself. The development of a production system has its own product development process. For example, the activity "analyse of utilization" could imply here an analysis of the lifecycle costs and productivity of the production system. A product of one company can be the production system of another company.

Layer - "strategy": A long-term framework is provided by different rules. These are different principles, which support the company to take a sustainable and advantageous market position. These are based on many business activities. For example, they can contain different business models and be cross generational. The general company's strategy and the product itself mutually influence each other. An important point is to manage the development strategy: here it is specified how an economic product policy can be reached, e.g., marketing program, diversity of variants, modular development, technologies and vertical range of manufacturing (e.g. [29]). For instance, detect strategy profiles: Determination of general characteristics, which can be used to derive the product portfolio. Hereby, the demands of the market and boundary conditions are used for a consequent orientation. In the strategy approach the activities "produce" and "model principle solution and embodiment" have to be treated differently. They are not conducted explicitly in the layer strategy, but have to be taken into account.

Each layer (product, strategy, production system, validation system) of the iPeM contains an individual system of objects. These individual systems of objects interact with each other. Thereby, they can exchange objects directly among themselves. In contrast, the system of objectives and the system of resources are modelled continuously. Thus, it is possible a) to model the different objectives of a company or a process in one single consistent system of objectives and b) to plan the total resources for a good overall result.

Concerning the results of the literature research and the empirical study the iPeM was adapted as follows. The iPeM has been expanded while maintaining modularity or even increasing it. Thereby, a holistic planning or a targeted development of the system of interest are possible at the same time. Furthermore, an overview of all sections and interfaces is given. Thus, orientation, transparency and a basis for communication is given. Moreover, the model supports the proactive planning of product generation engineering.

6. Conclusion

The results of the empirical study reveal that most of the participants are aware of the iPeM and evaluate it good. This can be tracked back to the fact to the survey among explicit iPeM-experts. Furthermore, the leading experts welcome the further development in the context of the product generation engineering, the modular design and the applicability for various purposes. These demands are as well mentioned in literature. By the adaption of the iPeM new project specific layers can be defined. This supports a broad application in research, education and practical development work.
Following works will evaluate the practical implementation of this model in different case studies. After ten years, another large-scale study is suggested.

References

[1] Albers A, Meboldt M. IPEMM – Integrated Product Development Process Management Model, Based on Systems Engineering and Systematic Problem Solving. In: *16th International Conference on Engineering Design*. Paris, France: 2007.

[2] Albers A, Düser, Burkardt N. Competence-profile oriented education with the Karlsruhe Education Model for Product Development (KaLeP). *World Trans. Eng. Technol. Educ. WTETE*, Bd. 5, 2006; S. 271–274

[3] Albers A, Reiß N, Bursac N, Walter B, Gladysz B. InnoFox – Situationsspezifische Methodenempfehlung im Produktentstehungsprozess. In: *Stuttgarter Symposium für Produktentwicklung 2015*, 2015.

[4] Gausemeier J, Ebbesmeyer P, Kallmeyer F. *Produktinnovation: Strategische Planung und Entwicklung der Produkte von morgen*. München and Wien: Hanser; 2001.

[5] Mantwill F. Es muss uns gelingen!. *Konstr. - Z. Für Produktentwicklung Ing.-Werktstoffe*, 2014, 2nd ed. p. 3, 2014.

[6] Albers A, Reiß N, Bursac N, Urbanec J, Lüdcke R. Situation-appropriate method selection in product development process – empirical study of method application. In: *Proceedings of NordDesign 2014 Conference*, 2014, p. 550–559.

[7] Albers A, Bursac N, Urbanec J, Lüdcke R, Rachenkova G. Knowledge Management in Product Generation Development – an empirical study. In: *Beiträge zum 25. DfX-Symposium*, 2014, p. 13–24.

[8] Albers A, Bursac N, Wintergerst E. Product Generation Development – Importance and Challenges from a Design Research Perspective. In: *New Developments in Mechanics and Mechanical Engineering*, 2015, p. 16–21.

[9] Albers A., Bursac N., Wintergerst E. Produktgenerationsentwicklung – Bedeutung und Herausforderungen aus einer entwicklungsmethodischen Perspektive. In: *Stuttgarter Symposium für Produktentwicklung 2015*, Stuttgart, 2015.

[10] Tomiyama T, Gu P, Jin Y, Lutters D, Kind C, Kimura F. Design methodologies: Industrial and educational applications. *CIRP Ann. - Manuf. Technol.*, 58 ed. 2, p. 543–565, 2009.

[11] Wynn D C, Clarkson P J. Models of designing. In: *Design process improvement: A review of current practice*, Springer London, 2005, p. 34–59.

[12] Gausemeier J, Lanza G, Lindemann U. *Produkte und Produktionssysteme integrativ konzipieren*. 2012.

[13] Pahl G, Beitz W. *Methoden und Anwendung erfolgreicher Produktentwicklung. Jörg Feldhusen, Karl-Heinrich Grote, editors*. 2013.

[14] Cooper R G. Third-Generation New Product Processes. *J. Prod. Innov. Manag.*, Bd. 11, Nr. 1, S. 3–14, Jan. 1994.

[15] Hall A D. *A Methodology for Systems Engineering*. Princeton, USA: van Nostrand, 1962.

[16] Lindemann U. Models of Design. In: *An Anthology of Theories and Models of Design*, A. Chakrabarti und L. T. M. Blessing editors, London: Springer; 2014. p. 121–132.

[17] VDI2221. VDI 2221 – Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte. 1993.

[18] Chrissis M B, Konrad M, Shrum S.*CMMI: Guidelines for Process Integration and Product Improvement*. Addison-Wesley, 2003.

[19] VDI2206. Entwicklungsmethodik für mechatronische Systeme. 2004.

[20] Cooper R. Stage-Gate Systems: A New Tool for Managing New Products. *Bus. Horiz.*, 33 ed. 3, p. 44–54, 1990.

[21] Browning T, Fricke E, Negele H. Key Concepts in Modeling Product Development Processes. *Syst. Eng.*, 9 ed. 2, p. 104–128, 2006.

[22] Albers A, Five Hypotheses about Engineering Processes and their Consequences. In *Proceedings of the TMCE 2010*, 2010.

[23] Lindemann U. *Methodische Entwicklung technischer Produkte: Methoden flexibel und situationsgerecht anwenden*. 2009.

[24] Albers A, Braun A, Muschik S. Ein Beitrag zum Verständnis des Aktivitätsbegriffs im System der Produktentstehung. In: *Tag des Systems Engineering*, 2010.

[25] Ropohl G. *Einleitung in die Systemtechnik*. München Wien: Carl Hanser; 1975.

[26] Albers A, Braun A. A generalised framework to compass and to support complex product engineering processes. *Int. J. Prod. Dev.*, 15 ed. 1/3, p. 6–25, 2011.

[27] Albers A, Burkardt N, Meboldt M, Saak M. SPALTEN problem solving methodology in the product development. 2005.

[28] Probst G, Raub S, Romhardt K. *Wissen managen: Wie Unternehmen ihre wertvollste Ressource optimal nutzen*. 6. ed. Wiesbaden: Gabler; 2010.

[29] Gausemeier J. *Strategische Planung und Integrative Entwicklung der Technischen Systeme von Morgen. Vorträge IW 42*. Ferdinand Schöningh Paderborn 2014, 2014.