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Systematic modeling of objectives and identification of reference system elements in a predevelopment project

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Abstract

Key factors for success of predevelopment projects are, among others, continuous validation and consensus building on objectives and the recurrent review thereof as well as the reduction of uncertainty in predevelopment projects.

This research evaluates the usage and added value of a systematic approach to explicitly model objectives during a predevelopment project. Thereby, providing insights into the elicitation, organization and validation of goals, requirements, constraints and their interrelations. The awareness, recurrent update and review of these by all members of the engineering team is crucial. Therefore, this research investigates consensus-building on objectives regarding the work setting and the explicit modeling of objectives. A main finding is that physical proximity of the members of the engineering teams has a critical influence on the consensus building regarding objectives. The ability of direct communication mitigates the perceived added value of the systematic modeling of objectives in this predevelopment project. Hence, the modeling of objectives does not support the consensus building with an adequate effort-benefit ratio. The software supported modeling of objectives is tested in a live-lab setting with seven product engineering teams with five to six members each as well as engineers from an industrial partner and a research facility. All members of the teams are regularly audited in milestones, dedicated interviews and workshops.

In this predevelopment project reference system elements are used to address the issue of uncertainty as reference system elements can be used to classify and manage necessary changes. As of now there is an eminent lack of methodology to support the identification of reference system elements aside of the predecessor and parts thereof. Several approaches to identify reference system elements used in this predevelopment project are collected with focus on methods utilizing objectives. The methods are categorized and the influence of modeling objectives on the method usage is discussed.

Keywords: model of objectives; team mental model, engineering design methods; team work

1. Motivation

In February 2018 Apple released a smart speaker called HomePod, which has been prone to leave behind a circular stain on wooden furniture caused by the silicone base [1]. This has caused an outrage among customers and is considered one of the reasons why the HomePod has a much smaller market share (5 %) than competing products from Amazon (70 %, Echo) and Google (25 %, Home) [2].

The competitors' products do not damage wooden surfaces. Thus, engineering teams at Amazon and Google probably have considered the placement of the speaker on wooden surfaces as use case, and in doing so they have elicited the corresponding requirements. Apple's engineers either have not classified this as a relevant use case, failed to elicit the corresponding requirements or neglected them. This example highlights the need of elicitation and validation of goals, requirements and constraints by considering relevant use cases, functions and stakeholders of the product in development as well as the need to identify relevant reference system elements.

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2. State of the art

2.1. Knowledge management

Knowledge is the interpretation and contemplation of the combination of well-understood information, facts and experience [3]. The management of knowledge is an essential activity in the product engineering process (PEP) [4–6].

The acquisition, structuring [7] and linking of knowledge to other knowledge and objectives is crucial. This helps to deal with shortening lead times in the PEP, the necessity of uniqueness of products and the adjustment to changing requirements [8–10]. Knowledge is organized in a knowledge base. Knowledge management is the continuous assessment of the validity of knowledge and update of the knowledge base as engineering relies increasingly on knowledge [11]. Proper knowledge management is crucial to the transfer of knowledge and reuse of information derived from past projects [12].

2.2. Systems engineering and requirements engineering

Systems engineering considers the design of the whole system by channelling the communication of all experts that are part of the PEP [13]. It intensifies interdisciplinary collaboration through the identification of interrelations between subsystems of the system in development (SiD) and the different involved disciplines [14]. Systems engineering requires an iterative top-down approach for engineering systems [15].

Requirements engineering is a derivative of systems engineering that specializes on the elicitation and organization of requirements. These are identified through the focus on customer needs and use cases [16].

The specifications of a complex SiD must be easily adaptable while displaying the impact of changes to allow the fast and easy integration of changes. As a result, a fixed definition of requirements, e.g. in a system specification or requirement [17,18] is no longer adequate [19,20].

2.3. Extended systems triple

The systems triple is a meta-model describing the analysis and synthesis activities during the PEP [21]. The system of objectives (SoO), the operation system and the system of objects comprise the systems triple. The SoO includes all goals, requirements and constraints. The operation system is comprised of the scope of possible solutions, the knowledge base and all resources available to the PEP. Resources include all available workforce, production capacity, computation capacity etc. [22]. The operation system controls all interactions between the SoO and the system of objects [23,24].

2.3.1. System of objectives

The system of objectives (SoO) consists of goals, requirements and constraints, hereafter referred to as objectives, and their interrelations [22,25,26]. Hence, the SoO is an advanced form of requirements engineering that represents requirements and their dependencies known to an individual of the product engineering team. It is crucial to identify conflicting elements of the SoO [27].Changing team members of the engineering teams, different customers and decision makers require a consistent modeling approach to ensure that all stakeholders related to the SiD have the same understanding [27].

2.3.2. Modeling the system of objectives

To ensure that every team member has the same understanding of the SoO, it has to be modeled [25]. According to Stachowiak [28] models are described by the three characteristics: representation, reduction and pragmatism. This implies that when modeling the SoO, the appropriate level of detail for the specific project must be used to ensure that the modeling has a favorable effort-benefit ratio. The choice of the software tool for the modeling is especially difficult, as accuracy of the model is negatively corelated to intuitive operation [25]. The distinct requirements of a predevelopment project must be considered individually for this decision prior to the initiation of the project [29,30].

2.4. PGE – Product Generation Engineering

Albers uses the model of product generation engineering (PGE) to describe product engineering projects [31], which is based on the assumption that engineering projects do not start from scratch and new products are engineered by the variation of several reference system elements (RSE) [32,33]. RSE are interconnected and can be found in existing systems or sub-systems in the company, other companies or even other business sectors.

The risk of development projects is reduced through adapting the RSE to the SiD [31,33]. There are three types of variation. Carry-over variations are variations with minimal modifications to be able to integrate the subsystem into the SiD [34] without altering the solution principle or embodiment of the RSE [35]. Embodiment variation refers to modifications in which the subsystem uses an adapted design, but the solution principle remains unchanged. A principle variation changes the solution principle, which is always accompanied by an embodiment variation, as the design used in the RSE must be adapted to the SiD [31].

2.5. Team mental models

Mental models are convenient small-scale models provided by human thought to predict events [36] and represent the truth according to premises such as statements and perception [37,38]. Mental models govern many essential aspects of human reasoning such as problem-solving, induction and deduction and human-machine interaction [39]. Individual system understanding and actions are controlled by mental models [40].

The concept of mental models can be adapted for collaborating individuals of a group [41] such as a team. These team mental models or shared mental models are then used to describe the shared comprehension of the team with regard to itself as a system and its tasks or objectives [42,43]. Team performance depends on the quality of the team mental model [44]. This quality depends on detail and accuracy as well as the extent to which the mental models of the team members align [45–47].

3. Methodology and approach

3.1. Research Environment

"IP – Integrated Product Development" is used as a research environment. IP is a cooperative predevelopment project of the product engineering institute of a large research facility and an industrial partner that changes every year. The industrial partner of this year's IP is a well-known machinery manufacturer. IP involves 41 graduate students, 14 engineers of the industrial partner and project management. Project management consists of four research associates of the institute and two project managers of the industrial partner's R&D department, one of them heading it. Each engineering team is comprised of six graduate students and two engineers, hereafter referred to as mentors, who collaborate closely. The industrial partner uses the open-mindedness of the interdisciplinary engineering teams in combination with the methodical expertise of the research associates to develop mechatronic systems [48]. Throughout IP, various additional experts of the industrial partner are consulted on specific technical topics. The product engineering institute provides methodical support for each of the seven teams, for instance, in workshops on knowledge management and PGE. After completion of the predevelopment project, the development is continued by various departments of the industrial partner until it obtains market maturity.

3.2. Research gap and research questions

Usually, the transfer of predevelopment projects to series development is accompanied by the transfer of new solution principles or a high variation of embodiment to different departments and engineers. A consistent and comprehensible model of objectives should be modeled during the predevelopment project to ensure a minimal loss of knowledge. The modeling organizes objectives and enables various members of the product engineering team to assess attainment of objectives. This prompts the following research questions:

- How were objectives elicited, organized and validated in an actual predevelopment project?
- What were the actual practices chosen by the engineering teams to build a consensus on the system of objectives?
- What was the perceived added value of systematic modeling of objectives?
- How were RSE identified in predevelopment projects?

Each team of the predevelopment project IP modeled a system of objectives (SoO) during the whole project. This modeled SoO was regularly discussed with the respective engineers of the industrial partner. Each member was expected to participate in the modeling of the SoO. Objectives were to be modeled hierarchical e.g. in a structured list. Throughout the project, the teams were frequently interviewed and advised by members of a research facility. In addition, at the end of the project a survey was conducted to identify means and methods of elicitation of reference system elements among the participants of IP. Fig.1. displays research activities such as interviews and surveys.

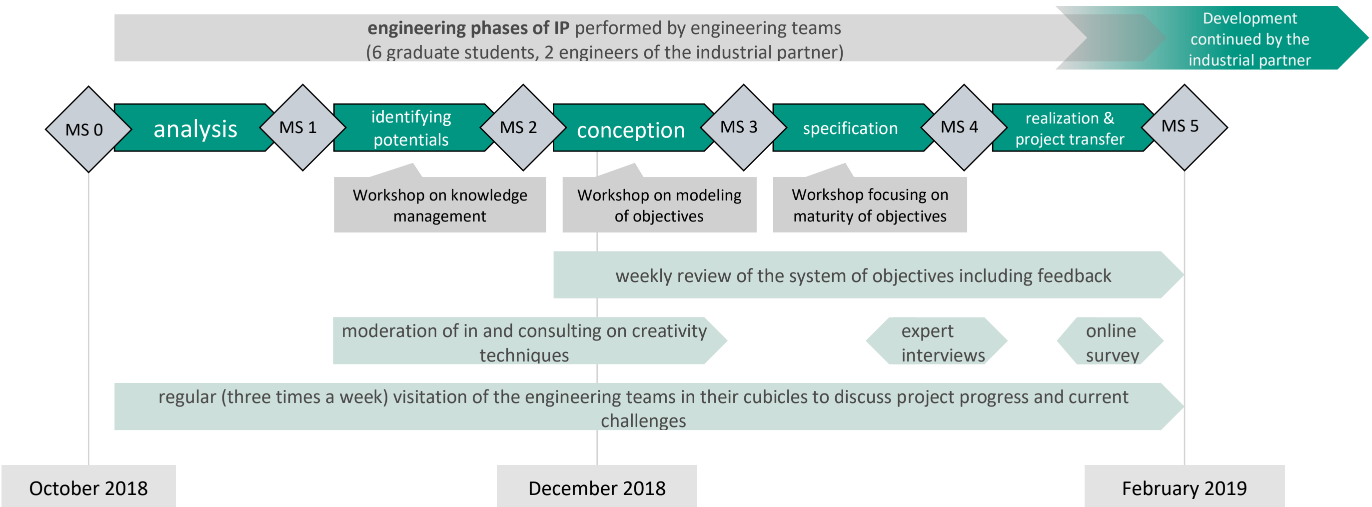

Fig. 1. Engineering phases of IP and research activities throughout the project

4. Case Study: Systematic modeling of objectives and identification of reference system elements in IP

The systematic that was used in IP to model the system of objectives (SoO) and to use the modeled objectives to identify reference system elements (RSE) is depicted in Fig. 2 as a

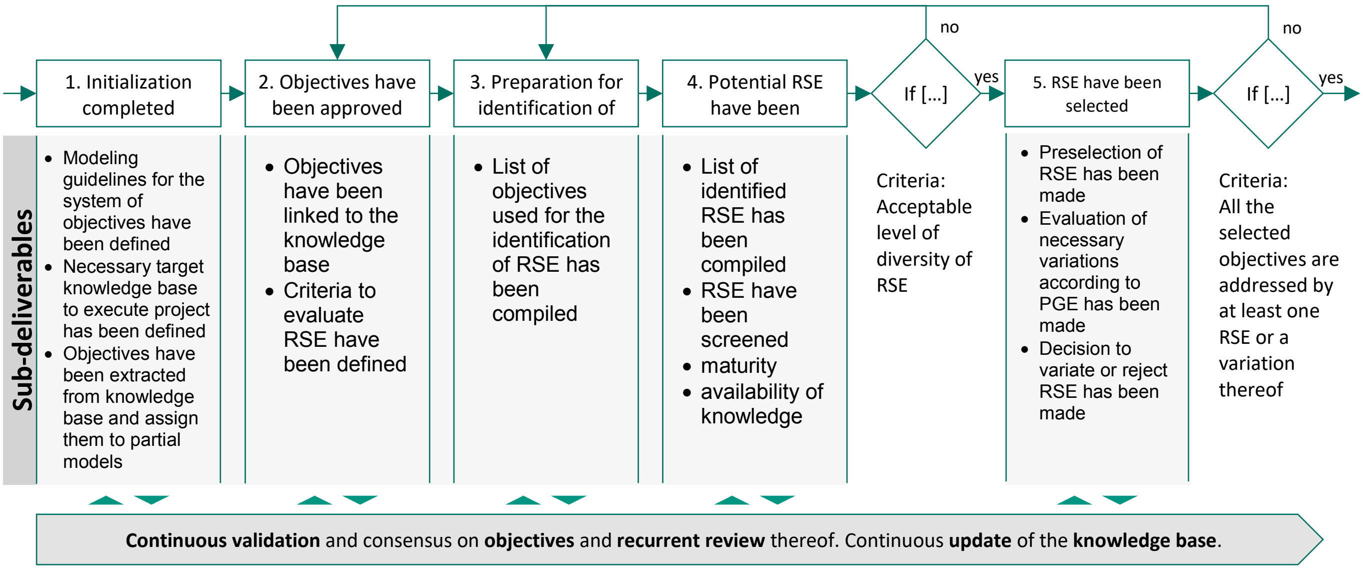

Fig. 2. Deliverables of the systematic to model objectives and use them to identify reference system elements

block diagram. The five main deliverables of the systematic do not coincide with the five engineering phases of IP. The systematic requires an idea for an innovation as input. This idea should include a description of the benefits for users, customers and the provider. This description includes a consideration of environmental and legal constraints. This means that the systematic (Fig. 2) can be applied to the IP process (Fig. 1) after milestone 2 (MS2). During the three phases following MS2, especially during the conception and the specification phase, the systematic was applied by the individual engineering teams. The systematic has been used by each engineering team on different sub-systems. Hereby, the first and second main deliverables, “Initialization completed” and “Objects have been approved”, were instructed and guided by project management. The last three main deliverables of the systematic (Fig. 2) were observed and discussed with the participants to ensure usability of the systematic in predevelopment projects.

The selection of RSE is succeeded by strategic planning of variations across multiple product generations according to the model of PGE and the planning of validation and verification activities of the SiD.

Main deliverable four and five are succeeded by a decision to either reiterate or advance based on previously defined criteria (Fig. 2). Reiteration can start at main deliverable two or three. After reiterating either the objectives have to be altered or the knowledge carriers, knowledge items or the scope used to identify RSE must be adapted. Either of these actions should enable the identification of additional RSE that utilize a different solution principle. A reiterating is not accompanied by a reduction of the knowledge base or the model of objectives.

4.1. Elicitation, organization and validation of objectives

In the project IP engineering teams chose to organize and structure their SoO in one or more tables using MS Excel. Objectives were elicited through an extensive research at the beginning of the project and detailed through expert knowledge, identification and analysis of use cases, different types of brainstorming, and inspections of various technical systems engineered by the industrial partner during operation. The excursions provided detailed insights into functional requirements and the perspective of an owner, operators and maintenance personal.

The SoO was not modeled and used as it was expected at the beginning of the IP project. Many objectives and their interrelations were not listed in MS Excel. Additionally, the SoO was modeled and maintained by a single team member. It was used to create an initial mental model of the SoO. However, the mental models of the team members were implicit and differed among the members of the engineering team.

Objectives were discussed with experts in milestone audits, weekly web conferences and visits of the sites of the industrial partner and thereby validated. Web conferences were supported by presentations and an agenda that all participants had previously agreed upon. The knowledge of the experts of the industrial partner was supplemented with excursions to customers of the industrial partner, trade fairs specific to the business sector and consultation with other institutes of the research facility.

4.2. Consensus building on the system of objectives

Several stakeholders complained about the lack of visualization of the SoO, e.g. by mind maps. Consequently, one team decided to model their SoO in a mind map using MindManager®. However, according to the interviews the use of the SoO of this team did not differ significantly from other teams. The interviewees attributed this to the physical proximity of all team members which allowed for direct and quick communication. As a result, the teams preferred discussion to the model of objectives modeled in a list or a mind map to build consensus on the SoO.

4.3. Perceived added value of a systematic modeling of objectives

Most of the IP participants perceived the modeling of the SoO mainly as a to-do and a mean to document team specific objectives. This implies minor added value. However, the interviewees acknowledged that the initial modeling of the SoO supports the creation of an initial team mental model and encourages the application of an objective-oriented rather than solution-oriented mindset. They suggested that the modeling of the SoO could improve the consensus building on SoO in a business context in which employees work on several projects at the same time, with different people in different locations.

4.4. Identification of reference system elements

According to interviews with the IP participants the means displayed in Table 1 were used to identify RSE during the project. The answers of the interviewees were clustered in the four categories research, interviews, discursive techniques and creativity methods. Discursive creativity techniques rely the evaluation, recombination and structuring of scientific knowledge, experience and results of creativity sessions [17]. Intuitive creativity techniques are strongly related to sudden inspiration [17].

Table 1. Methods to identify reference system elements.

Category	Method
Research	Internet
	Trade fair
	Technical literature
	Patent
	Company and business sector analysis
	Field trips
Interviews	Experts
	Individual network
Discursive creativity techniques	Bionic
	Morphologic box [49]
	Design catalogue (in combination with C&C² [50]
	Design by analogy[51]
	TRIZ
Intuitive creativity methods	Brainwriting /Brainstorming
	Method of negation and construction[49]
	6-3-5- brainwriting
	Emotive word/imagines/questions
	Six thinking hats [52]

Some teams used a selection of objectives in combination with a discursive technique to identify RSE. One approach was to select a set of objectives and to use these to identify technical systems that had one or more objectives in common with the SiD.

Next, for each selected RSE a SoO was inferred and compared to the SoO of the SiD. Depending on the similarity of the two models, either a new RSE was selected for evaluation or the model of PGE was used on the RSE. The necessary variations needed to integrate the RSE into the SiD were classified. This followed by a decision regarding its rejection or implementation.

5. Discussion

It is crucial for the elicitation of objectives and their validation to experience relevant technical systems in operation, including their surrounding and their interfaces. This increases the individual understanding of the SiD to a level that allows the engineering teams to address specific issues during the expert discussions. Statements and comments of the experts are better understood, and the engineering team is able to put them in context and to infer objectives from these. The mentors of the industrial partner have a significant impact on the elicitation and validation of objectives and track the progress and attainment of objectives in weekly reviews both regarding the whole project and the upcoming milestone.

Although the teams are instructed to model the system of objective (SoO) together, the modeling is done by one distinct person, as responsibilities are assigned to a specific team member. Often, this coincides with the responsibility of documentation. In this predevelopments project modeling the SoO in lists or mind-maps does not increase performance as was initially expected [25], which is due to physical proximity of the team members in their cubicle [53,54]. This means that teams quickly achieve a consensus on the SoO as the proximity reduces inhibitions of team members to interact and team members quickly gain each other's trust [55]. This enables them to discuss objectives and discrepancies of their mental models at any time. Thus, the benefits and the perceived added value of modeling the SoO with a software did not justify the effort. This might differ in case of distributed work settings. Hereby, the explicit form of objectives is likely to be used differently as team members lack the ability of direct communication, meaning nonverbal, emotional and visual communication is limited [56]. In these instances, the SoO might support formal and visual communication.

In predevelopment projects the identification of RSE relies mainly on brainstorming, discussion and other creativity methods. The quality of the results of discussions and creativity methods profits from diverse team members as they stimulate each other's thoughts and the individual knowledge and experience. Additionally, the professional networks of team members can significantly support the assessment of validity, meaning the RSE can be varied according to PGE to integrate it in the SiD. Once functions, properties or characteristics of the SiD are known discursive techniques can be used to identify RSE. This requires a consensus on the SoO and relatively high level of detail of the objectives that have been selected to be used in the discursive technique. However, this benefit remains unknown to the teams and therefore is not perceived as added value.

6. Outlook

Further research is required to explore the transferability of the system of objectives (SoO) between product generations. This research should observe the potential change in usage and perception of the value added by modeling the SoO for several consecutive product generations and their derivatives. Another interesting aspect is to validate the benefits of modeling the SoO in distributed work settings.

Additionally, research should explore means to support engineering teams in their utilization of the SoO to identify RSE using discursive techniques (e.g. TRIZ) as well as methodical support for the classification of necessary variation of the RSE according to PGE.

References

[1] Apple Support. *Cleaning and taking care of HomePod*. https://support.apple.com/en-us/HT208435 (accessed on 09.01.2019).

[2] Cao P. *CIRP: HomePod marketshare steadily growing, still behind Amazon and Google*. https://9to5mac.com/2018/11/06/cirp-june-2018-homepod-report/ (accessed on 09.01.2019).

[3] Davenport TH, Long DW de, Beers CM (1998) Successful knowledge management projects. *Sloan management review* 39(2):43–57.

[4] Albers A, Reiß N, Bursac N, Schwarz L, Lüdcke R (2015) Modelling Technique for Knowledge Management, Process Management and Method Application - a Formula Student Exploratory Study. in Schabacker M, Gericke K, Szélig N, Vajna S, (Eds.). *Modelling and Management of Engineering Processes*. Springer Berlin Heidelberg. Berlin, Heidelberg, pp. 151–162.

[5] Romer PM (1990) Human capital and growth: Theory and evidence. *Unit Roots, Investment Measures and Other Essays, Vol.* 32(1):pages 251-286.

[6] Kujawski E (2013) Analysis and Critique of the System Readiness Level. *IEEE Trans. Syst. Man Cybern, Syst.* 43(4):979–87.

[7] Lindemann U, (Ed.) (2016) *Handbuch Produktentwicklung*. Carl Hanser Verlag GmbH & Co. KG, München.

[8] Raudberget D, Ström M, Elgh F (2018) Supporting Innovation and Knowledge Transfer from Individual to Corporate Level. in Peruzzini M, Pellicciari M, Bil C, Stjepandić J, Wognum N, (Eds.). *Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0: Proceedings of the 25th ISPE Inc. International Conference on Transdisciplinary Engineering*. IOS Press, pp. 576–585.

[9] Collier B, DeMarco T, Fearey P (1996) A defined process for project post mortem review. *IEEE Softw.* 13(4):65–72.

[10] Xu Y, Bernard A (2011) Quantifying the value of knowledge within the context of product development. *Knowledge-Based Systems* 24(1):166–75.

[11] Amelingmeyer J (2004) *Wissensmanagement: Analyse und Gestaltung der Wissensbasis von Unternehmen*. Deutscher Universitätsverlag, Wiesbaden.

[12] Desouza KC, Evaristo JR (2006) Project management offices: A case of knowledge-based archetypes. *International Journal of Information Management* 26(5):414–23.

[13] Booton RC, Ramo S (1984) The Development of Systems Engineering. *IEEE Trans. Aerosp. Electron. Syst.* AES-20(4):306–10.

[14] Schulze S-O (2016) Systems Engineering. in Lindemann U, (Ed.). *Handbuch Produktentwicklung*. Carl Hanser Verlag GmbH & Co. KG. München, pp. 153–184.

[15] Eisner H (1997) Essentials of project and systems engineering management. *Choice Reviews Online* 34(08):34-4492-34-4492.

[16] Walden DD, Roedler GJ, Forsberg K, Hamelin RD, Shortell TM, Kaffenberger R, (Eds.) (2017) *INCOSE Systems Engineering Handbuch: Ein Leitfaden für Systemlebenszyklus-Prozesse und -Aktivitäten INCOSE-TP-2003-002-04 2015*. GfSE e.V, München.

[17] Pahl G, Beitz W, Feldhusen J, Grote K-H (2007) *Engineering design: A Systematic Approach.* 3rd ed. Springer, London.

[18] Cross N (2008) *Engineering Design Methods: Strategies for Product Design.* 4th ed. Wiley; Chichester: John Wiley, Hoboken, N.J.

[19] Darlington MJ, Culley SJ (2002) Current research in the engineering design requirement. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 216(3):375–88.

[20] Albers A, Ebel B, Lohmeyer Q, (Eds.) (2012) *Systems of Objectives in Complex Product Development*, Karlsruhe.

[21] Matthiesen S, Meboldt M, Lohmeyer Q (2012) The Dilemma of Managing Iterations in time-to-Market Development Processes. in Heidig P, (Ed.). *Proceedings of the 2nd International Conference on Modelling and Management Engineering Processes*. Univ. Cambrigde, UK, pp. 127–140.

[22] Albers A, Lohmeyer Q, Ebel B, (Eds.) (2011) *Dimensions of Objectives in Interdisciplinary Product Development Projects*.

[23] Ropohl G (1979) *Eine Systemtheorie der Technik: Zur Grundlegung der allgemeinen Technologie*. Carl Hanser Verlag, München, Wien.

[24] Ropohl G (2009) *Allgemeine Technologie eine Systemtheorie der Technik*. KIT Scientific Publishing, s.l.

[25] Albers A, Klingler S, Ebel B (2013) Modeling System of Objectives in Engineering Design Practice. in Lindemann U, Venkataraman S, Kim YS, Lee SW, Clarkson J, Cascini G, (Eds.). *ICED 13, the 19th International Conference on Engineering Design: 19th-22nd August 2013, Sungkyunkwan University (SKKU), Seoul, Korea*. Design Society. Milton Keynes, UK.

[26] Albers A (2010) Five Hypotheses about Engineering Processes and their Consequences. in Horváth I, (Ed.). *Tools and methods of competitive engineering:*

Proceedings of the Eighth International Symposium on Tools and Methods of Competitive Engineering - TMCE 2010, April 12 - 16, Ancona, Italy. Faculty of Industrial Design Engineering Univ. of Technology. Delft.
[27]Richter T, Albers A, Birk C, Rapp M, Bursac N (2018) A Training Framework for the Synthesis of a Consistent System of Objectives in Modular Design. *Procedia CIRP* 70:398–403.
[28]Stachowiak H (1973) *Allgemeine Modelltheorie.* 1st ed. Springer-Verlag Wien, Wien.
[29]Andriole SJ, Freeman PA (1993) Software systems engineering: the case for a new discipline. *Softw. Eng. J. UK* 8(3):165.
[30]Stapel K, Knauss E, Allmann C (2008) Lightweight Process Documentation: Just Enough Structure in Automotive Pre-development. in Baddoo N, Messnarz R, Smolander K, O'Connor RV, (Eds.). *Software Process Improvement: 15th European Conference, EuroSPI 2008, Dublin, Ireland, September 3-5, 2008. Proceedings*. Springer. Berlin, Heidelberg, pp. 142–151.
[31]Albers A, Bursac N, Rapp S (2017) PGE – Produktgenerationsentwicklung am Beispiel des Zweimassenschwungrads. *Forsch Ingenieurwes* 81(1):13–31.
[32]Albers A, Rapp S, Heitger N, Wattenberg F, Bursac N (2018) Reference Products in PGE – Product Generation Engineering: Analyzing Challenges Based on the System Hierarchy. *Procedia CIRP* 70:469–74.
[33]Albers A, Rapp S, Spadinger M, Richter T, Birk C, Marthaler F, Heimicke J, Kurtz V, Wessels H (2019) *Das Referenzsystem im Modell der PGE – Produktgenerationsentwicklung: Vorschlag einer generalisierten Beschreibung von Referenzprodukten und ihrer Wechselbeziehungen*. Karlsruhe.
[34]Albers A, Rapp S, Birk C, Bursac N, (Eds.) (2017) *Die Frühe Phase der PGE – Produktgenerationsentwicklung*.
[35]Albers A, Bursac N, Wintergerst E, (Eds.) (2015) *Produktgenerationsentwicklung: Bedeutung und Herausforderungen aus einer entwicklungsmethodischen Perspektive*.
[36]Craik KJW (1943) *The Nature of Explanation*. Cambridge University Press, Cambridge.
[37]Johnson-Laird PN (2001) Mental models and deduction. *Trends in Cognitive Sciences* 5(10):434–42.
[38]Johnson-Laird PN (1980) Mental Models in Cognitive Science. *Cognitive Science* 4(1):71–115.
[39]Thagard P (2010) How Brains Make Mental Models. in Magnani L, Carnielli W, Pizzi C, (Eds.). *Model-based reasoning in science and technology: Abduction, logic, and computational discovery / [edited by] Lorenzo Magnani, Walter Carnielli, Claudio Pizzi*, 1st ed. Springer. Berlin, pp. 447–461.
[40]Wilson JR, Rutherford A (1989) Mental Models: Theory and Application in Human Factors. *Hum Factors* 31(6):617–34.
[41]Albers A, Lohmeyer Q, Turki T (2012) Transfer of engineering experience by shared mental models. *International Conference on Engineering and Product Design Education*.
[42]Reynolds R, Blickensderfer E (2009) Crew Resource Management and Shared Mental Models: A Proposal. *JAAER*:15–24.
[43]Lim B-C, Klein KJ (2006) Team mental models and team performance: a field study of the effects of team mental model similarity and accuracy. *J. Organiz. Behav.* 27(4):403–18.
[44]Salas E, Prince C, Baker DP, Shersta L (1995) Situation Awareness in Team Performance: Implications for Measurement and Training 37(1):122–36.
[45]Klimoski R, Mohammed S (1994) Team Mental Model: Construct or Metaphor? *Journal of Management* 20(2):403–37.
[46]Converse S, Cannon-Bowers JA, Salas E (1991) Team Member Shared Mental Models: A Theory and Some Methodological Issues. *Proceedings of the Human Factors Society Annual Meeting* 35(19):1417–21.
[47]Levine JM, Moreland RL (1990) Progress in Small Group Research. *Annu. Rev. Psychol.* 41(1):585–634.
[48]Albers A, Bursac N, Heimicke J, Walter B, Reiß N, (Eds.) (2017) *20 years of co-creation using case based learning An integrated approach for teaching innovation and research in Product Generation Engineering*. Springer-Verlag Berlin Heidelberg 2011.
[49]Zwicky F, Wilson AG, (Eds.) (1967) *New Methods of Thought and Procedure: Contributions to the Symposiom on Methodologies*. Springer-Verlag New York Inc, New York.
[50]Matthiesen S, Grauberger P, Hölz K, Nelius T, Bremer F, Wettstein A, Gessinger A, Pflegler B, Nowoseltschenko K, Voß K (2018) Modellbildung mit dem C&C²-Ansatz in der Gestaltung - Techniken zur Analyse und Synthese.
[51]Moreno DP, Hernández AA, Yang MC, Otto KN, Hölttä-Otto K, Linsey JS, Wood KL, Linden A (2014) Fundamental studies in Design-by-Analogy: A focus on domain-knowledge experts and applications to transactional design problems. *Design Studies* 35(3):232–72.
[52]Bono E de (1999) *Six thinking hats.* 1st ed. Back Bay Books, Boston.
[53]Hoegl M, Proserpio L (2004) Team member proximity and teamwork in innovative projects. *Research Policy* 33(8):1153–65.
[54]Bjørnson FO, Wijnmaalen J, Stettina CJ, Dingsøyr T (2018) Inter-team Coordination in Large-Scale Agile Development: A Case Study of Three Enabling Mechanisms. in Garbajosa J, Wang X, Aguiar A, (Eds.). *Agile Processes in Software Engineering and Extreme Programming: 19th International Conference*. Springer. Cham, pp. 216–231.
[55]Innes JE, Booher DE (1999) Consensus Building and Complex Adaptive Systems. *Journal of the American Planning Association* 65(4):412–23.
[56]Cascio WF (2000) Managing a virtual workplace. *AMP* 14(3):81–90.