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A SYSTEMATIC APPROACH TO MODEL OBJECTIVES IN PREDEVELOPMENT PROJECTS

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ABSTRACT

This contribution presents a systematic for the elicitation of objectives and the utilization of objectives to identify reference products. The systematic is based on existing meta models. The model of objectives as proposed in this research eases decision-making and outlines the next validation activities. A key success factor is the project transferability between teams, which is often necessary in predevelopment. This is ensured through comprehensibility of objectives which benefits from the linkage between the model of objectives and the knowledge base. The proposed systematic is applied to a predevelopment project which is used as case study. In the case study it has been shown that objectives can be used to identify reference products. The approach is validated in a live-lab setting with seven engineering teams with six graduate students, two engineers of an industrial partner and a research associate. Several workshops were used to train all members of the teams in the systematic. The effects of the systematic are assessed in dedicated interviews, a survey as well as with observation of the engineering teams during milestones and engineering activities between milestones.

Keywords: Integrated product development, Systems Engineering (SE), Requirements

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1 INTRODUCTION

There are frequently problems during the project handover from predevelopment to series development due to comprehension problems. One reason for this are incomprehensible objectives (Cooper, 1988). Many development projects fail due to the lack of consideration of relevant objectives, requirements and constraints and their interrelations and the recurrent update and review thereof (Holder *et al.*, 2017).
This paper presents a systematic for the elicitation of objectives and the utilization of objectives to identify reference products. The systematic is based on the systems triple which is a meta model originally developed for single individuals. It describes analysis and synthesis activities during the product engineering process (Albers, 2010). A core aspect of the systematic is the modeling of objectives and their interrelations to provide basic understanding and thus enable more effective discussion and communication. Another core aspect is the identification and evaluation of reference products.
The systematic is validated in a live-lab setting with seven engineering teams. Each of the seven teams consists of six graduate students, one research associate and two mentors from an industrial partner. Several workshops were used to train all team members in the proposed systematic. Afterwards, the engineering teams were supported during the implementation process. The project results are recurrently audited in milestones. Additionally, the core team of the predevelopment project evaluates the progression at least twice a week. Furthermore, the effects of the systematic are assessed in dedicated interviews and a survey.

2 STATE-OF-THE-ART

2.1 Systems engineering and requirement engineering

Systems engineering is an interdisciplinary approach that allows the realization of successful systems by providing adequate methods and processes (Schulze, 2016). It is an iterative top-down process for the design, development and operation of a usable system (Eisner, 1997). Therefore it is imperative to identify customers' and providers' needs and demands, necessary functionality and the documentation of all requirements before design and validation (Walden *et al.*, 2017). Systems engineering deals with the whole system and coordinates experts of various subsystems and disciplines to ensure integral success (Booton and Ramo, 1984). This success is a result of the satisfaction of all requirements and demands of customers, users and the provider.
Several methods to model and to elicit requirements exist. Traditional methods of elicitation include questionnaires, interviews and surveys to gather data. Other approaches are based on stakeholder involvement, prototyping and consensus-building workshops (Nuseibeh and Easterbrook, 2000).
Traditional techniques to model requirements are based on a specification sheet which is at its core a mere list of requirements. Complex engineering processes can no longer treat specifications as a firmly defined document. Instead they must treat specifications as an open medium, suitable to transfer "the functional and performance requirements" and required technical adaptions (Darlington and Culley, 2002, p. 381). Hence, it is necessary to model relations between objectives and requirements as well as to identify all relevant stakeholders and their demands. Systems engineering and its corresponding tools are currently used to address this issue (Buede and Miller, 2016). However, in predevelopment projects objectives, requirements and constraints change frequently. In combination with complicated systems in development this leads to high complexity (Allmann, 2007). Various models and tools are used to cope with the resulting complexity of analyzing the whole system including its interrelations, (Booton and Ramo, 1984). Models for the iterative top-down process are the waterfall model, the spiral model or the object-oriented design which are incorporated in software tools (Buede and Miller, 2016). The complexity causes high effort to model the objectives in predevelopment projects (Summers and Shah, 2010). In the object-oriented modeling approach Unified Modeling Language (UML) is used as a specification language to model objects at multiple levels of abstraction. Thus, various perspectives at different levels of abstraction and detail can be considered. UML is established as standard in software engineering.
Various perspectives can be modeled by using partial models (Stechert, 2010, p. 41). Expert interviews conducted in previous research show that the nine partial models; functions, embodiment/ implementation, engineering activities, use case, objectives, milestones and deliverables, stakeholder, test and requirements suffice for the product engineering process (PEP) (Ebel, 2015). When modeling

different aspects in partial models it is essential that the models are consistent and continuous. Consistency means that different disciplines do not contradict each other. Partial models must not contradict with progression in the product life cycle or modification of the model's granularity, which refers to continuity (Albers and Lohmeyer, 2012).

Many recent systematics of product engineering for modeling objectives evolve around SysML, a derivative of UML, of which some are supported by software tools (DOORS, Enterprise Architect, IRqA, OSRMT, Cameo, etc.). However, these tools are highly specialized and difficult to master. Therefore, only specialized experts are able to understand and benefit using these tools (Ebert, 2012, 327-334). This means an engineering team needs a dedicated expert for modeling requirements of the system in development (SiD) with a company specific tool. As only very few engineers are used to systems engineering tools there has not been the necessity to implement compatibility with existing software, like MS Office products, in an organization (Ebel, 2015).

2.2 The systems triple and the integrated product engineering modell (iPeM)

The systems triple is an approach to model the analysis and synthesis activities during the product development process (Matthiesen *et al.*, 2012). It consists of the following subsystems: system of objectives (SoO), operation system and system of objects. Figure 1 depicts the systems triple, its components and how they relate to each other. The SoO and the systems of objects interact through the operation system only. The operation system includes the knowledge base and the scope of all solutions. The analysis of the system of objects yields the knowledge base. The SoO is derived from the knowledge base through synthesis thereof. The system of objects contains all results of the product development process such as prototypes, calculations or explicit knowledge e.g. in the form of a wiki or reports (Albers *et al.*, 2011).

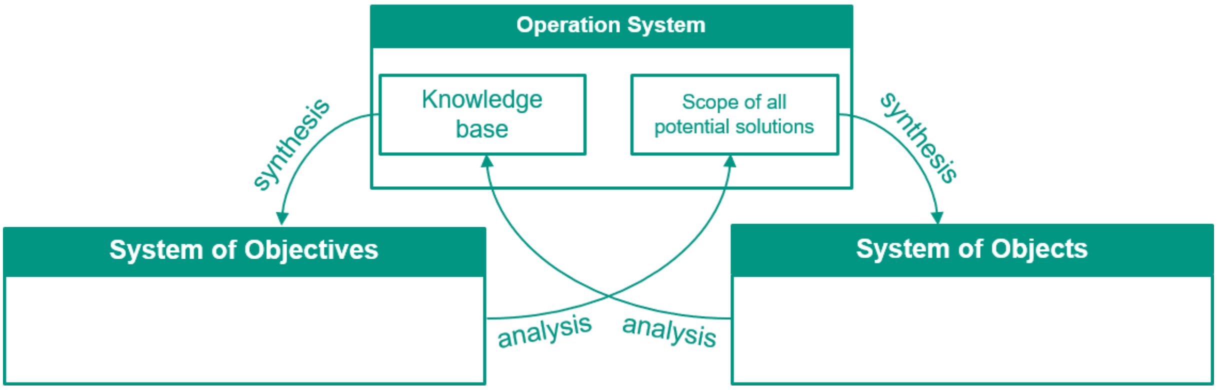

Figure 1. Systems triple based on (Matthiesen et al., 2012)

The SoO specifies and organizes goals, requirements, constraints and their interrelations, hereafter referred to as objectives, based on, among others, use cases and stakeholders. The SoO is an integral part of product engineering (Albers, 2010; Albers *et al.*, 2011) as it documents decisions of decision-makers and provides detailed information on the criteria a product must meet. All objectives must be comprehensible and justified (van Lamsweerde, 2004; Mohagheghi and Aagedal, 2007).

Most products are engineered in interdisciplinary teams with different backgrounds and approaches etc. Thus, it is crucial to provide a model that predefines necessary development activities of the PEP. The iPeM - integrated Product engineering Model is a general model of product engineering. This includes development of the product, production process and production system, and other activities throughout the lifecycle with significant relevance to product engineering (Albers, 2010). The iPeM provides a framework for the systems triple. The iPeM aims to fill the gap between process management and engineering.

2.3 PGE - Product generation engineering

Albers approaches the transition between product generations by means of the model of product generation engineering (PGE). PGE is understood as the development of technical products, whereby the changes in subsystems are divided into three categories. Carryover variation adopts the solution principle and embodiment from a reference product without any changes. As a result, minimal adjustments are made to integrate the reference product (RP) into the SiD (Albers *et al.*, 2017b).

Embodiment variation is a possibility to develop new subsystems from a reference product. The same solution principle is used but the design is altered. For a principle variation, the solution principle of the RP is changed. The principle variation always includes an embodiment variation, as design used in the respective concept must be adapted to fit the solution principle.
PGE is based on the understanding that no development project starts from scratch and every new product is developed based on several RP. Risks and challenges in the PEP correlate with the share of newly developed subsystems which have a high level of embodiment and principle variation. Additionally, an influence that has to be considered is the extent to which engineers possess information and experience about a RP (Albers *et al.*, 2018).

3 AIM OF RESEARCH & METHODOLOGY

3.1 Research environment

The predevelopment project "IP - Integrated Product Development", a collaborative project between an industrial partner and the product engineering institute of a research facility, is used as research environment. The industrial partner of this year's IP is a major machinery manufacturer. In this project two experts of the industrial partner, hereafter referred to as mentors, work together with one team of six graduate students. The mentors of the engineering teams are in constant exchange with the engineering team using various platforms (WebEx, Email, telecommunication, JIRA and face-to-face). The mentors validate objectives and the knowledge base thoroughly. Furthermore, they connect their engineering team with experts from other departments of the industrial partner and customers of the industrial partner. Each engineering teams is assigned to a research associate who provides methodological support. The combination of open-mindedness of the graduate students, the expertise of the industrial partner and the methodological know-how of the research associates facilitates development of systems with high innovation potential. After completion of the engineering phases of the predevelopment project, development is continued by the industrial partner to attain market maturity. This means that the industrial partner utilizes the proposed systematic in its professional development as well. Due to confidentiality agreements only the systematic and not the resulting products of IP are discussed in this paper.

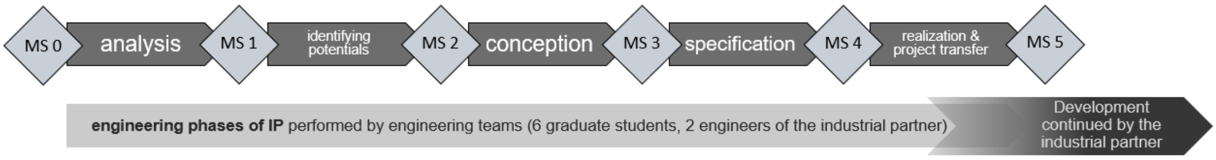

Figure 2. Process of IP - Integrated Product Development

Figure 2 illustrates the five engineering phases of IP. Each phase corresponds to a milestone in which the experts working with teams and experienced project managers are able to monitor progress and decide on the concepts or ideas to be pursued. Additionally, next steps and deliverables of the upcoming phase or the transfer are defined and explained (Albers *et al.*, 2017a).

3.2 Research questions

The analyzed literature shows that in predevelopment, the created system of objectives (SoO) must be comprehensible. This eases the hand-over of a project or system in development (SiD) to another department. This is the case if objectives have been defined and are comprehensible to the new department. Furthermore, the level of attainment of individual objectives should be known by the new department. This applies not only to the transfer of an entire project from one department to another, but also for different individuals working on it.
In interdisciplinary predevelopment projects the system engineer often lacks expert knowledge in subsystems. Due to this lack of expertise and limited time the system engineer cannot check every objective for correctness and level of attainment. Experts focus on their respective subsystems and rely on system engineers to support them by modeling interrelations. Predecessors of IP have shown that while a knowledge base was created in the first project phase, the full potential was not exploited in the following phases. This increased the difficulty to include experts and transfer the project to the industrial partner. This emphasizes the need to incorporate means to support the use of the knowledge base.

The analysis of the system of objects yields the knowledge base thus it is crucial to identify relevant reference products (RP). These potentially provide new insights such as requirements, constraints or functionality that must be considered during the engineering of the SiD. Furthermore, RP can be used to estimate the risk of the SiD to miss its invention target, it is necessary to support identification of non-trivial RP. This enables the system engineer to select the RP with the best fit for a specific set of objectives. Therefore, a systematic is needed that includes the modeling of the SoO and the utilization thereof to identify RP.

This leads to the following research questions:

- What was the impact of linking the knowledge base and the system of objectives in the predevelopment project?
- What were the criteria of the engineering teams for selecting a software tool to model the system of objectives during the predevelopment project?
- How did the modeling of the system of objectives support the identification of reference products?
- What activities to evaluate the fit of reference products were observed in the predevelopment project?
- Which influences of the reference products on decision-making concerning financial and technical feasibility were observed?

The five steps of the systematic described in 4.1 were executed in the predevelopment project IP. For the first step of the systematic methods purpose and quality and type of results are defined. For the consecutive steps of the systematic the purpose and results are defined. The approaches used by the engineering teams during step two to five were observed in the case study.

The research questions are answered through semi-structured interviews and an online survey. The interviews were conducted with the project management, graduate students and mentors of the engineering teams. The online survey was answered by 38 of the 41 graduate students. Additionally, the engineering teams are observed during milestones and workshops. Furthermore, the engineering teams are recurrently consulted concerning the SoO, creativity methods, preparation of pitches for the milestones and are given specific instructions which aspects require further elaboration.

4 RESULTS

Chapter 4.1 describes the proposed systematic and the meta models it is based on. Chapter 4.2 describes the case study and answers the research questions.

4.1 Systematic to model and validate objectives in predevelopment projects

The proposed systematic is derived from the systems triple and instructs a system engineer how to implement and utilize the iPeM in the product engineering process (PEP).

The iPeM provides a framework in which the systems triple, process management and engineering activities can be linked (Albers, 2010). The systematic is based on the systems triple. This means that the knowledge base results from the analysis of the system of objects and the continuous synthesis of the knowledge base yields the system of objectives (SoO) (Matthiesen *et al.*, 2012).

The systematic focuses on the modeling of objectives and the use thereof. The system of objects of IP is comprised of reference products (RP), milestone results, research results, calculations and other objects created during the PEP. The proposed systematic uses objectives to identify RP. These RP can potentially alter the system of objects.

The proposed systematic is based on the five following steps illustrated in Figure 3

1. modeling of the initial system of objectives of the system in development and the continuous validation and updating thereof
2. identification and evaluation of reference products,
3. inferring the system of objectives of selected reference products
4. comparison of the system of objectives of the product in development with the one of the reference products.
5. decision if and how reference products shall be used.

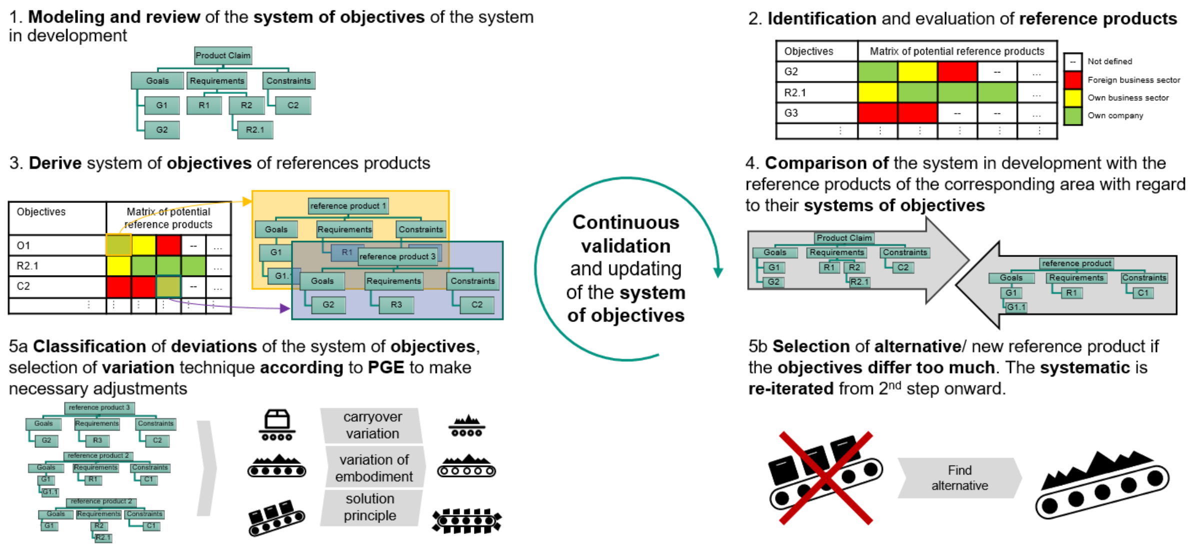

Figure 3. Systematic to elicit objectives and use objectives to identify reference products

The first step of the systematic is to create an initial SoO which then must be recurrently updated and reviewed. It is not sufficient to do this just once at the beginning as new information might emerge during the progression of the project. This happens due to altered constraints or requirements or the identification of new objectives that have to be added such as stakeholders or needs of stakeholders. The SoO is explicitly modeled e.g. by using a software tool or post-its. During training session on modeling objectives teams started to model the SoO with a white board or post-its. This proofed to be beneficial in determining the basic structure including the partial models to be used but has limitations due to the maximum number of objects possible to display. The explicit modeling is important, as every member of the engineering team and all decision-makers should be able to understand and modify the SoO. Engineering teams may use a different set up of the SoO with at least partially deviant partial models. The number and type of partial models depends on effort-to-benefit ratio and short-term benefit. Short-term benefit means that the systematic proofs to be beneficial within two phases of IP. Effort-to-benefit ratio and short-term benefit are determined by various influences such as disciplines, characters and experience of the team members, the complexity of the SiD, the duration of the project and the organizational setting of the project. However, teams must model at least the three partial models: goals, requirements and constraints and their interrelations as these are the basis of the SoO (Ebel, 2015).
The second step is the identification of RP. This is achieved through the abstraction of objectives and comparison between the functions and objectives of the SiD with other technical systems. With the support of this systematic it is possible to identify additional RP even form other business sectors. This is succeeded by reverse engineering of the SoO of the RP. It is easier to reverse engineer a sufficient SoO from well-known RP than it is from a RP of a different business sector. If the RP is part of the company portfolio, system requirements and interviews with the respective project leader and experts nominated by the project leader can be used to reverse engineer the SoO. The SoO of the RP from a competitor is likely to remain at a much less detailed level as stakeholders and use cases are at least partially unknown.
In the following step the systems of objectives of the reference product and of the SiD is compared to assess the possibility of transforming the RP into the SiD.
In a final step, necessary adjustments on the RP are specified by utilizing the approach of PGE, Figure 3 illustrates this using the example of conveyor belts. The RP is incorporated into the SiD. If it is not viable to make the required changes another RP should be selected.

4.2 Case-study and application in an interdisciplinary predevelopment project

The implementation of the systematic, described in 4.1, in the predevelopment project “IP - Integrated Product Development” was based on experiences of previous predevelopment projects. In this year’s IP information was stored in a wiki on a MS SharePoint which is used by all teams. Each team has a dedicated subdomain on the SharePoint to exchange data with the industrial partner and to document its progress. A tagging system links the SoO to the wiki. The systems engineers of the engineering teams are responsible for eliciting, elaborating, structuring, specifying and modifying objectives, hereafter referred to as modeling. The purpose of the SoO and goal-oriented requirements engineering is similar. The SoO has a stronger focus on the modeling of interrelations. To increase awareness for interrelations system engineers use the SoO to model their objectives in this predevelopment project. This enables mentors, members of the core team and other stakeholders to validate project results without physical presence.

At the beginning of each phase, a target agreement is created consisting of deliverables defined by a research facility and to-dos defined by the industrial partner. Deliverables are phase-specific project results, that are defined on an abstract level which each team must deliver. Afterwards, the target agreement is reviewed and approved from the mentors. Based on the target agreement, objectives for prototypes are derived, which are evaluated and approved by mentors, too. The repeated review loops ensure an effective development as the objectives are validated thoroughly.

4.2.1 Impact of linking the knowledge base and the system of objectives

The linkage of the knowledge base to the SoO ensures comprehensibility and substantiation of objectives (Ebel, 2015). In the case study, mentors of the industrial partner functioned as experts that validate the SoO regularly. Engineering teams frequently discussed modified or new objectives with their mentors from the industrial partner or experts involved for a particular topic. The validated SoO was then used to decide on major next steps by the decision panel in milestones.

A comprehensive tagging system was used to implement the linkage. Different topics on the SharePoint were marked with tags. These tags were found in the model of objectives, milestone presentations, target agreements, etc. Thus, tags enable the quick retrieval of relevant information form the wiki. This means the SoO represents and connects the current objectives of the SiD. Tags are the linkage between the SoO and the knowledge base. They indicate the origin of information thereby justifying an objective and making it more comprehensible for all stakeholders of the PEP. For instance, requirements can be traced back to a specific statement from an expert or customer of the industrial partner.

4.2.2 Criteria of the engineering teams for selecting a software tool to model the system of objectives

The engineering teams chose the software tool they used during IP with the following criteria. The most important criteria are the effort-benefit ratio and the total effort for modeling the SoO in the software tool. Total effort refers to the maximum effort that engineering teams were willing to invest into modeling the SoO independent of the effort-benefit ratio. Another important criterion is the comprehensibility of the SoO, followed by the learnability which can be split into two separate aspects. One aspect is previous knowledge of the software. The other aspect is the time required to master a program. Table 1 shows the software tools considered from the engineering teams.

Table 1. Software tools considered for modeling the system of objectives during IP

Type	Software tool	Weakness/strength
Systems Modeler	Cameo Systems Modeler iQUAVIS	+comprehensibility +high effort-benefit ratio -high effort -learnability
Table/list	MS Excel MS Access	+little effort +learnability -comprehensibility (lack of visualization)
Graphical	MS Visio MS PowerPoint	+comprehensibility +learnability -effort-benefit ratio
Mind map	Mind Manager	+learnability +comprehensibility

Teams focused solely on criteria related to modeling effort and neglected criteria related to the quality of the model of the SoO. Six of the seven engineering teams chose to use MS Excel for modeling their SoO. Excel proved to be sufficient in the initial stages of the project but lacked in comprehensibility in later stages of the project as the SoO grew more complex since it was difficult to grasp hierarchy and interrelations. The engineering teams attributed this to the lack of visualization. Consequently, one engineering team chose to model their SoO in a mind map using MindManager which increased comprehensibility. However, the unfiltered display of hierarchy and all known interrelations made the mind map somewhat confusing during the very late stage of the predevelopment project.

4.2.3 Observed support of identification of reference products by modeling the system of objectives

The engineering teams used a selection of objectives to identify RP. The selected objectives were utilized in various creativity methods to identify technical systems that serve as RP. The selected objectives were used in discursive (morphologic box), intuitive (635 brainstorming) or combinatorial (TRIZ) creativity techniques to identify RP. Many teams used methods like brainstorming, emotive imagery. However, individual teams used a more structured approach by using TRIZ, morphologic box and six-thinking hats. For example, one team used six-thinking hats to identify RP for sensor networks and an algorithm to evaluate sensor data.

4.2.4 Observed activities to evaluate the fit of reference products

First constraints and use cases of the RP were compared to the SiD. This was followed by an analysis of required functionality and requirements of the RP for a particular use case. For instance, in the case study an engineering team regarded the use case of a stressed operator and the implications on the user interface. Another team considered the operation on muddy ground.
The analysis is used to determine which objectives of the SiD were not satisfied by the RP. This is followed by an evaluation of the possibility to adapt the RP to meet the previously unsatisfied objectives. Another criterion to assess the fit of a RP was the technological readiness of the RP. In step five of the systematic engineering teams assessed the complexity and adaptability of the RP which correlates with the type of variation according of PGE.

4.2.5 Observed influences of the reference products on decision-making concerning financial and technical feasibility

The RP were analyzed to assess the technical and financial feasibility of the SiD. Technical feasibility was assessed based on an approximation of the necessary variations and technology readiness of the RP. During this process mentors were heavily involved. Next, competence, expertise and manufacturing capacities of the industrial partner regarding designing and manufacturing the RP were evaluated. This was done by interviewing relevant experts. In case that RP could not be manufactured by the industrial partner the engineering teams suggested manufacturers.
The industrial partner preferred RP that are manufactured by existing partners and provides the industrial with ample alternatives in sourcing. The evaluation of the RP is complemented by an examination of the patent situation.

5 CONCLUSION & DISCUSSION

In this case study it could be observed that the linkage of the knowledge base and the SoO provides an overview on the status of the project and substantiates decisions. This coincides with findings of Erman (Erman *et al.*, 1980). Additionally, results of the predevelopment project are linked to the knowledge base as the purpose and extent of results such as prototypes is derived from the SoO. This increases comprehensibility and eases transferability of the project to previously uninvolved engineers.
Modeling the SoO and its linkage to the knowledge bases increase the understanding of the system. In order to validate the objectives, it is necessary to link them to the knowledge base and thereby substantiating them. This substantiation results in transparency and traceability. Thus, integration and variation of subsystems is eased, since awareness of system borders and interfaces is increased. In line with Ebel (Ebel, 2015) all team members profit from a greater awareness of objectives. An additional finding of this research effort is the possibility to use the SoO as a mean to document project results, which proved beneficial in the late stages of IP including the transfer to the industrial partner. The benefits of increased awareness of objectives and documentation through the SoO were confirmed by reports of all teams and the core team of IP. Hence, it was possible to identify subsystems with the greatest impact on the attainment of objectives. This aligns with previous findings (Schulze, 2016, p. 181).

In the beginning of the predevelopment project the teams chose MS Excel to model objectives. This can be explained by the previous knowledge of the software which leads to a small initial effort. Additionally, the ability to filter Excel lists easily with built-in functionality seemed sufficient to ensure comprehensibility of the SoO. In the late stages of the project the built-in functionality did no longer suffice due to the high number of interrelations of objectives. The engineering team that was modeling the SoO with MindManager™ had similar problem though not as severe. These problems can be attributed to the lack of consideration of criteria not related to effort in the process of choosing the tool to model the SoO. It is notable that systems modelers were not used despite their capabilities of handling a multitude of objectives and visualize them appropriately. This can be attributed to the total effort required to learn and operate a systems modeler.
While engineering teams confirmed added value the SoO for the identification of RP, some of them would have appreciated support selecting objectives to be used in creativity methods to identify RP. The teams were not instructed to use specific creativity methods.

6 OUTLOOK

Further research is required to evaluate the influence of visualization of the comprehensibility of the SoO. This research showed that engineering teams need to have the option to choose objectives and details to be displayed.
This contribution discusses the benefit linking the knowledge base to the SoO regarding the elicitation of objectives. In a next step the impact of the knowledge base on the assessment of attainment of objectives should be investigated.
During the project IP the steps two to five of the proposed systematic were observed. Consecutive research should focus on using the insights of this paper to provide guidelines and identify appropriate methods for each step.

REFERENCES

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.

Albers, A., Bursac, N., Heimicke, J., Walter, B. and Reiß, N. (Eds.) (2017a), *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.

Albers, A. and Lohmeyer, Q. (2012), “Advanced systems engineering. Towards a model-based and human-centered methodology”, In: Horváth, I. (Ed.), *Tools and Methods of Competitive Engineering: Proceedings of the Ninth International Symposium on Tools and Methods of Competitive Engineering, Tmce 2012, May 7-11, 2012, Karlsruhe, Germany ; Digital Proceedings*, Faculty of Industrial Design Engineering Delft University of Technology, Delft.

Albers, A., Lohmeyer, Q., Quentin, Ebel, B. and Bjoern (Eds.) (2011), *Dimensions of Objectives in Interdisciplinary Product Development Projects.*

Albers, A., Rapp, S., Birk, C. and Bursac, N. (Eds.) (2017b), *Die Frühe Phase der PGE – Produktgenerationsentwicklung*.

Albers, A., Rapp, S., Heitger, N., Wattenberg, F. and Bursac, N. (2018), “Reference products in pge – product generation engineering: analyzing challenges based on the system hierarchy”, *Procedia CIRP*, Vol. 70, pp. 469–474. http://doi.org/10.1016/j.procir.2018.02.046.

Allmann, C. (2007), “Automobile vorentwicklung, anforderungsmanagement auf der grünen wiese”, *GI Softwaretechnik-Trends*, Vol. 27 No. 1.

Booton, R.C. and Ramo, S. (1984), “The development of systems engineering”, *IEEE Transactions on Aerospace and Electronic Systems*, Vol. AES-20 No. 4, pp. 306–310. http://doi.org/10.1109/TAES.1984.4502055.

Buede, D.M. and Miller, W.D. (2016), *The Engineering Design of Systems: Models and Methods*, John Wiley & Sons, Incorporated, Hoboken, New Jersey.

Cooper, R.G. (1988), “Predevelopment activities determine new product success”, *Industrial Marketing Management*, Vol. 17 No. 3, pp. 237–247. http://doi.org/10.1016/0019-8501(88)90007-7.

Darlington, M.J. and Culley, S.J. (2002), “Current research in the engineering design requirement”, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 216 No. 3, pp. 375–388. http://doi.org/10.1243/0954405021520049.

Ebel, B. (2015), “Modellierung von Zielsystemen in der interdisziplinären produktentstehung”, Dissertation, Institut für Produktentwicklung (IPEK), Karlsruher Institut für Technologie (KIT), Karlsruhe, 2015.
Ebert, C. (2012), *Systematisches Requirements Engineering: Anforderungen ermitteln, spezifizieren, analysieren und verwalten*, Vol. 4., überarb. Aufl., dpunkt-Verl., Heidelberg.
Eisner, H. (1997), “Essentials of project and systems engineering management”, *Choice Reviews Online*, Vol. 34 No. 08, pp. 34-4492–34-4492. http://doi.org/10.5860/CHOICE.34-4492.
Erman, L.D., Hayes-Roth, F., Lesser, V.R. and Reddy, D.R. (1980), “The hearsay-ii speech-understanding system: integrating knowledge to resolve uncertainty”, *ACM Computing Surveys*, Vol. 12 No. 2, pp. 213–253. http://doi.org/10.1145/356810.356816.
Holder, K., Zech, A., Ramsaier, M., Stetter, R., Niedermeier, H.-P., Rudolph, S. and Till, M. (2017), “Model-based requirements management in gear systems design based on graph-based design languages”, *Applied Sciences*, Vol. 7 No. 11, p. 1112. http://doi.org/10.3390/app7111112.
Matthiesen, S., Meboldt, M. and 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.
Mohagheghi, P. and Aagedal, J. (2007), “Evaluating quality in model-driven engineering”, In *International Workshop on Modeling in Software Engineering (MISE 2007): Proceedings, ICSE 2007 workshops [20-26 May 2007, Minneapolis ICSE 2007, Minneapolis, MN, USA, 5/20/2007 - 5/26/2007*, IEEE, Piscataway, N.J., p. 6. http://doi.org/10.1109/MISE.2007.6.
Nuseibeh, B. and Easterbrook, S. (2000), “Requirements Engineering”, In: Finkelstein, A. (Ed.), *The future of software engineering, Limerick, Ireland, 6/4/2000 - 6/11/2000*, ACM, New York, pp. 35–46. http://doi.org/10.1145/336512.336523.
Schulze, S.-O. (2016), “Systems Engineering”, In: Lindemann, U. (Ed.), *Handbuch Produktentwicklung*, Carl Hanser Verlag GmbH & Co. KG, München, pp. 153–184.
Stechert, C. (2010), “Modellierung komplexer anforderungen. Bericht Nr. 75”, Dissertation, Institut für Konstruktionstechnik, Technische Universität Braunschweig, Braunschweig, 2010.
Summers, J.D. and Shah, J.J. (2010), “Mechanical engineering design complexity metrics: Size, coupling, and solvability”, *Journal of Mechanical Design*, Vol. 132 No. 2, p. 21004. http://doi.org/10.1115/1.4000759.
van Lamsweerde, A. (2004), “Goal-oriented requirements enginering: A roundtrip from research to practice”, In *12th IEEE international requirements engineering conference, Kyoto, Japan, Sept. 6-10, 2004*, IEEE, pp. 3–6. http://doi.org/10.1109/ICRE.2004.1335648.
Walden, D.D., Roedler, G.J., Forsberg, K., Hamelin, R.D., Shortell, T.M. and Kaffenberger, R. (Eds.) (2017), *INCOSE Systems Engineering Handbuch: Ein Leitfaden für Systemlebenszyklus-Prozesse und -Aktivitäten INCOSE-TP-2003-002-04 2015,* Deutsche Übersetzung der vierten Ausgabe, GfSE e.V, München.