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Creating innovative products with reference system elements - a case study on approaches in practice

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Abstract

As any other human being development engineers preferably act based on experience. Hence it is comprehensible that even for a product that initially appears revolutionary usually one or more references can be found. This enhances, for example, the comparability or the availability of a products subsystems so that they are more easily to deal with. Especially during the development of a new product, which means the start of a new product line, the use of reference system elements helps to reduce development efforts. Reference system elements are, for example, physical products whose functions or components are relevant for one's own product. By scanning the system of objectives for smaller subsystems one may find those functions or components just mentioned. For this scientific work a development process of a technology rollout was examined. The objective pursued was to gain insights on possibilities and challenges of deriving knowledge from such reference system elements in this specific case. A suitable research environment was offered by a medium sized machine manufacturer. A new technology to process foam particles using radio frequency is being developed there. The established process using steam is already in the high-end range, which is why only a small development potential is left. From the findings in this case study in synthesis with the state of the art on innovation management and knowledge management a descriptive process model is derived. The focus of the process model is to support the search for relevant reference system elements. For the examined machine, for example, the common microwave was used as a reference element. The elements found can be evaluated for their suitability using previously elaborated validation criteria. This facilitates the adoption of existing solutions or the development of new solutions based on reference system elements.

Keywords: Product Generation Engineering – PGE; Reference System; New Product Development – NPD; Knowledge Management; Innovation Management;

1. Introduction

In 2000, the elevator industry faced a major innovation with the development of aramid ropes by Schindler. Discovered in climbing applications, fully synthetic elevator ropes are produced by processing aramids. These clearly surpass steel ropes in winding radius and weight and thus save space whilst featuring comparable minimum breaking forces. The installation of carbon fibres in the rope enables electronic monitoring of wear. [1] The consecutive improvement of ropes made of steel would probably not have yielded such potential. The change in technology is described by FOSTER as necessary for a product to maintain competitive as the technical potential of a technology is exhausted after a certain period [2]. The integration of a new technology in an existing product leads to a big proportion of new development. One accompanying challenge here are participants' knowledge gaps at the beginning. Not least as the integration of (external) existing solution principles into the own product requires interdisciplinary competencies. These may not be present in the own company yet [3]. For this scientific work a retrospective study was carried out to investigate the use and importance of reference products and foreign competencies. Similar to the example described before, a product with a high proportion of new developments was examined, where the technical challenge there was to change a machines' process from utilizing steam to radio waves.

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2. State of the Art

2.1 The Model of PGE - Product Generation Engineering

The model of PGE – Product Generation Engineering describes the development of new products. Its basis are two main hypotheses [4]. First, every product development builds up on already existing technical systems and corresponding documentation, for example product models, requirement lists or test reports. Those references can come from different existing technical systems. The complete set of elements from already existing technical systems and their documentation, which serve continuously as a basis and starting point for the development activities for a new product, and their interactions, is called "reference system" [5]. Consequently, one can perceive the development of every new product as the development of a new product generation. This also applies to the development of a first generation of a specific product as it is also always based on a reference system. Reference system elements can come from other products of a certain company, but also from competitor's products, research projects or technical concept descriptions from other branches, for example. The reference system in a development process changes during the process and needs to be actively developed by looking for potential reference system elements, evaluating and selecting them. Second, the development of a new product consists, based on the reference system, of three types of variation of subsystems. Some subsystems are directly carried over from the reference system to the new product and only adjusted at their interfaces due to system integration. This is called carryover variation (CV). Other subsystems of a new product emerge by changing the embodiment or the principle of a subsystem from the reference system. This is embodiment variation (EV) or principle variation (PV), respectively. All subsystems together, which result from EV and PV, form the share of new development in a new product generation. EV and PV as well as the use of reference system elements from outside a company bring along chances like establishing improved or new product features or the integration of new technologies but also technical and by that economical risks. [6] The reason for those risks is a lack of knowledge, either due to technical novelty or due to a limited accessibility, for example of the documentation of products from outside a company [7].

2.2 Invention processes for products with a high proportion of new developments

For companies to differentiate themselves from their competitors, they can for example, equip an existing product for a new generation with a high proportion of new developments [5]. These products, from a PGE point of view product generations 1 (G_1), represent the invention of a new technology or the combination of several technologies that are to be introduced to the market. Through successful placement and the securing of market shares, a product generation 1 becomes an innovation.[8] At the beginning of its development process, the main objective is to maximize the performance of the product so that it can prevail in competition with products of the same or a similar use. In following steps the products diversity is expanded and finally production costs are reduced. [9] During this process, technical know-how is gained and the technological potential of a company is capitalized [10]. This know-how just mentioned can be "imported" to a certain extent into the own company by the employment of experts since this knowledge represents an important resource for the development process. It is possible, however, that the integration of expertise foreign to the company's own is difficult. [11] An approach to quantify this problem is given by the insights on cognitive distance. Cognitive distance is the name of a description model by NOTEBOOM ET AL. whose purpose is to measure the disparity of the "organizational focus" between two development partners [12]. In cooperation between companies, a distinction is made between exploring and exploiting[3]. Exploring cooperation includes a high degree of uncertainty, since existing design rules have to be overcome. However, this also provides the opportunity to generate a high innovation potential. In contrast, the focus of exploiting cooperation lies on the optimisation of existing solutions. The results of several case studies show that cognitive distance has a more positive effect on innovation performance in exploring cooperation than in exploiting ones.

Based on the research on cognitive distance as well as on exploring and exploiting cooperation, ENKEL /DÜRMÜLLER/ GASSMANN developed the approach of cross-industry-innovation[1]. Their contribution refers to the adoption of solution principles across industry boundaries through the search for analogies[13]. In the context of cross-industry-innovation it is assumed that a cooperation is formed between two companies. One of the two provides its solution to open up access to new markets (inside-out). The counterpart uses the existing solution principle or even know-how to strengthen its own core competence (outside-in). The cognitive distance between the partners, or the lack of competence that both partners have, can be identified by a thorough evaluation of the competence profiles.

Another possibility to find and implement new solution principles for products of the own portfolio is given by technology scouting [14]. This can be done by the companies own experts or outsourced to service providers [15,16]. The selected scout will then look at the state of the art of research and technology in either a specific technological field or make undirected observations to identify relevant developments. In contrast to the strategic approaches of Technology Management, or the Technology Foresight, the core of the Technology Scouting consists in the procurement of information for, and evaluation of technological solutions for initially identified needs. [14]

2.3 The influence of knowledge management on the determination of objectives

The system triple describes the product development process with three interacting systems: the system of objectives, operation system and system of objects [17]. This paper focuses on the system of objectives and its interdependencies to the other two elements of the system triple. Systems of objectives always refer to a system of objects and can be divided into subsystems of objectives, which consequently also refer to subsystems in the system of objects. [18] The creation of it begins with an initial system of objectives. During the extension inconsistencies can occur which have to be identified by the operation system. To achieve this, the system of objectives is validated continuously [19]. The elements of the system of objectives are then adjusted accordingly. [20] Inconsistencies are reduced by the possibility of relating individual elements of the system of objectives. Resulting systems of objectives, if done right, represent the desired state of a product development process holistically. [20]Inconsistencies occur in the system of objectives partly due to knowledge gaps of the operation system. These can be filled utilizing need-based knowledge management. MCMANUS AND HASTINGS count knowledge gaps among other uncertainties that can occur in a product development process. These result from "facts that are not known, or are known only imprecisely, that are needed to complete the system architecture in a rational way. "[21]. The knowledge required for this can already be available both internally and externally. Internal knowledge is increasingly becoming a competitive factor for companies [22]. Therefore, an organized storage of knowledge as well as its purposeful mediation at the right time, is worthwhile. Product generations 1 often require additional competence in the development process. As a result, the interdisciplinarity of the problem-solving team may increase. Here the exchange of highly specific knowledge is inevitable. A distinction is made between implicit and explicit knowledge as follows. “Implicit knowledge is bound to persons, difficult to communicate and hardly formalizable” [22]. “Explicit knowledge can be formalized at various levels (e.g. language, writing) and thus communicated and stored in various media”[22]. The popular research by North containing the knowledge stairway can be used to describe how a company's knowledge base grows. It also becomes apparent how implicit knowledge, e.g. that of an expert, can be shared. As soon as explicit knowledge - as information - has been made available, it must be internalized by the respective addressee. Only if knowledge has been put into context, or experiences have been made concerning it, this knowledge turns into competence. [23]

3. Aim of research and methodology

In research on new product development, it is often assumed that an invention is mostly based on knowledge that has already been generated [24].This knowledge can be exploited in different ways for one's own product. Examples of this are the analysis of competing products or analogous solutions from distant industries, seen on the example of the elevator ropes [25]. The approach of this scientific work is to synthesize insights gained in a case study with the state of the art by using and developing the two basic hypotheses of PGE. Additionally the search for and use of the external knowledge mentioned is to be substantiated. For this purpose, the following research questions were asked:

- What possibilities are there for finding reference system elements (RSE)?
- Which purpose served the use of reference system elements observed in the case study?
- How can the search for reference system elements be systematized based on existing description models, in particular PGE?

In a literature review, it is recorded how construction methodology for interdisciplinary teams can support the development of a product generation with a high proportion of new developments through the practical use of knowledge management. Here the focus laid on the finding and integration of external Know-How in the form of RSE. Furthermore, to investigate in what form these external RSE can be integrated, suggestions made in literature were collected.

As research environment for the observation on the purpose of the use of RSE during the case study served the development process on a new technology for particle foam machines. In continuous coordination with the core of the development team and the head of development, the process was examined retrospectively. In the run-up to the investigations, an analysis was carried out of the functionality of the current machine using steam. Subsequently, the physical basics of the new machine using Radio frequency (RF) technology were examined before the different competencies in the project team were allocated since both the mechanical and electrical engineering knowledge had to be covered. Furthermore, the variations compared to the previous generation were recorded. A two-staged study was carried out to distinct which know-how was integrated through the use of in-house RSE and which was integrated supported by using RSE from outside the company. The first stage took place during two on-site meetings and the second stage via three video telephone calls. Throughout the entire study, the head of development continuously verified whether the observations recorded represent the development process correctly. The focus during the first stage laid on reconstructing the system of objectives. For this purpose, the development process was divided into four subjects, each of which was examined with a different team member: 1. Industrial partners, 2. Material data base, 3. Implementation, 4. Series production ready. In the second stage, reference system elements were to be identified. In contrast to the first stage, the same guide document was dealt during the interviews with the team-members, whereby it was adjusted after each interview based on previous findings. In preparation, the reference system elements were initially categorised to be able to elicit the possibly subconscious or self-evident approach of the experts on using reference system elements. For the same reason, various milestones of the project were selected, and relevant subsystems of the machine were identified. The results of the analysis on the system of objectives were also used (stage 1). Elements of it that trigger a new development were of particular interest.

To point out interdependencies with existing descriptive models on product development, a practical approach is derived to support the systematic search and usage of reference system elements during the development of a product generation with a high proportion of new development. It is based both on literature review and the case study. In the first it was examined what approaches on systematically finding and dealing with external Know-How are there already. In the case study the focus laid on how developers, individually or as a team, subconsciously proceed methodically to close existing knowledge gaps on the one hand and to search for alternative solutions for the new development share of the product on the other hand. Here, the resulting changes on the machines' architecture were analysed. For this purpose, both the newly added subsystems and technologies for the realization of the new generation and the subsystems and technologies abandoned on the way there were recorded in a system, analysed and the consequences of their use assessed.

Section 4 answers the three formulated research questions separately. While section 4.1 gives an overview of the research environment and the gained insights, the other sections deal specifically with one of the research questions in each case, following the order in which they were set up.

4. Case Study: Initiation of a new product line of particle foam machines by implementing a new technology

4.1 Observations

Research was carried out in the field of manufacturing molded parts made of particle foam. For the conventional production method saturated steam is used to carry the energy needed to heat the mold (tool) and sinter, colloquially ‘foam’, the foam particles. After sintering, the molded parts must be stabilized by cooling. A press force is needed to absorb the force exerted by the expanded material and to prevent the leakage of steam. Using steam comes in with limitations on “foamable” materials. As the steam’s temperature is controlled by setting it under pressure, materials with a higher melting point require an immense steam pressure. This leads to unreasonably stressed machine parts.

The investigated project started with the usage of a patent of an uncompetitive Japanese company, from which the principle - foam particles sintered by radio waves - is derived. The development and implementation of this technology requires expertise in the field of high-frequency technology. This was acquired for the development process from an uncompetitive company as it was not previously available in the company. This way knowledge gaps in high frequency Know-How could be reduced drastically. Then a feasibility study was done. Provisional tests were carried out at companies with the appropriate equipment. To convince employees and managers internally who had concerns regarding the technology change, a household microwave was used for demonstration purposes. However, it was already known at that time that the microwave wavelength of 12.2 cm was unsuitable to produce larger molded parts due to the inhomogeneous resulting electromagnetic field. When selecting a larger wavelength, it is mandatory to use the ISM bands[26] of the Federal Network Agency. This selection process led to the use of radio waves with a length of 11m. The radio waves must be provided by a high-frequency generator. Due to a lack of resources, the company did not develop its own radio wave generator. As a complex purchased part, its implementation had to be supported by the manufacturer. As a condition for entering a cooperation, the requirement was that at least one RF engineer was employed in the concerning company to reduce cognitive distance to the cooperating partner. In sequence a cooperation with a company manufacturing film sealing machines was established. These consist, besides the generator, of a power adjustment and a press. All these subsystems are needed for the particle foam machine as well. The power adjustment and the press are not suitable for the own process. However, with simple tools and small quantities of foam particles, the first tests could be carried out in such a film sealing machine. By doing this, a knowledge base on HF technology and the behavior of foam particles in the EM field was established. For further investigations the machine was rented. This was followed by the construction of a prototype, for which only the generator could be used. The power adjustment had to be specially developed for this purpose. The press and the remaining machine architecture were carryover from previous product generations. To be able to control the quality of the molded parts, it is necessary to know and/or adjust the decisive influencing factors. These are e.g.: Homogeneity of the EM-field, dielectrical properties of certain components, Thermic of the in-mold process. Therefore, a laboratory was set up to create a database and the necessary know-how. The computer-aided simulation of the process is only possible after the collection of this data.

4.2 Underlying process of the case study

4.2.1 Possibilities to find reference system elements (RSE)

In the following a broad range of possible RSE is listed. This specific selection is made based on suggestions of the cross-industry-innovation approach (see state of the art) and extended based on literature reviews and advice by the experts interviewed during the case study.

Patents, technologies (internal and external), implicit knowledge of colleagues, technical literature, examples in nature, business models or processes, reference products, standards/conventions/laws, physical effects, standard solutions, own technical experience.

4.2.2 Purpose of using reference system elements observed in the case study

Given the possibilities to find RSE above characteristics and effects of reference system elements observable in the described case are listed in Table 1:

Table 1. Purpose of reference system elements observed in case study

Observation	**Effect**	**Corresponding RSE**
Use of radiofrequency technology	Lack of competence ➔ know-how integration	Radiofrequency technology
Use of radiofrequency technology	Scepticism ➔ short-term available possibility of demonstration	Microwave
Radio waves are used for broadcast and military	Corresponding standards and laws become relevant	ISM-Band
Other use-cases of radio frequencies to process plastics	Possibilities of integrating existing solutions → cooperation	PVC-Machine
Development of other company on RF-technology	Here patent-free ➔ No licence costs but also no possibility to get own patent	Patent
Material data has to be acquired and knowledge base for its behaviour expanded	Fast availability of prototype → focus on functionality; low share of new development	Components of previous generation

4.2.3 Systematization of the search for reference system elements based on existing description models

The text passages numbered below the illustration (Fig. 1) do not represent a direct one-to-one assignment to the footnote in the illustrations. Instead, the meaning of the individual actions is synthesized (e.g. Knowledge gaps, Extension and

Initial system of objectives are merged in Define need for action).

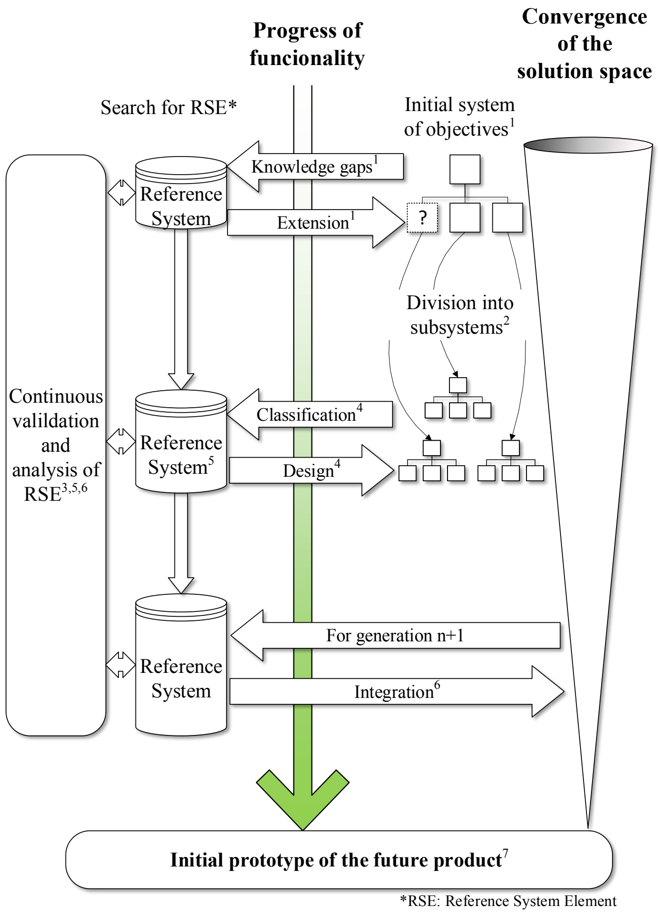

Fig. 1: Developed process model

Define need for action[1]

Before the start of the development process, a product profile is set up. This is followed by an initial system of objectives that describes the objectives, boundary conditions and requirements known at the time. Existing RSE support this process, for example the constraints of a previous product generation apply for a new one as well or in parts.

Dividing the product into subsystems[2]

The planned product is divided into subsystems to be able to assess how extensive the change must be since parts of earlier product generations can be carried over. For this purpose, the subsystems are selected which are to be further developed and which can be adopted. It is also possible to delete existing subsystems or add new ones. If there is no previous version of the desired product, the subsystems to be carried over can be purchased parts. Defined interdependencies between the subsystems make it clear how variations affect each other.

Validation criteria for each varying subsystem[3]

Validation criteria in this context are criteria that are defined at the beginning of the product development process and may be adjusted during the process. They must be set up for the overall product in general and then individually for the respective varying subsystems. This tests the suitability for inclusion in the development process of both new elements of system of objectives and new reference system elements. The basic idea of validation is condensed in the question: "Is the right product being developed?" [19]. While this is a customer-oriented perspective, the use of validation criteria gives the answer to the question: "does the integration of this new element lead to the development of the right product?".

System of objectives for each varying subsystem[4]

Now, the desired state is defined for the varying subsystems, branching off from the initial system of objectives. This is done in parallel or iteratively to the search for reference system elements. Newly acquired knowledge improves the consistency of the system of objectives, while the more precise desired state facilitates the search for relevant RSE.

RSE for each varying Subsystem[5]

The search for RSE is the core of the process model. By dividing the product into subsystems, one obtains "functioning solution spaces" for which research and/or development has possibly already been carried out. This can be used for the own product development process, if it is publicly available or assessed through cooperation.

Classifying RSE/Choose concept[6]

The reference system elements found must now be evaluated. The validation criteria are used to compare the desired state for the product with the actual state at the RSE. If this discrepancy (actual/desired) is combined with an estimation of the implementation effort required to incorporate the RSE, conclusions can be drawn about the economic efficiency. In this way, the danger of producing an (economic) erroneous development can be prevented. Physical RSE should be tested, if possible without commitment, i.e. during a company visit or for rent. This also allows the system of objectives to be extended, as such tests improve the understanding of the problem to be solved. If several RSE have been found for a subsystem that contain different solutions, a solution concept should be selected for the prototype design.

Construction of prototype[7]

Once a concept has been selected for realisation as a prototype, design can begin. You are in the so-called 'Design Freeze'. Again, the design and testing of the prototype will make the system of objectives more precise and the prototype will become an RSE for future versions. In addition, RSE can be used to support commissioning. For example, the expertise of the manufacturer of the HF-generator was consolidated for the implementation in the moulding machine.

5. Conclusion

In In this research work, possible triggers for the search for reference system elements RSE were identified (RSE) and which follow-up activities arise as implications. These findings can be used to derive necessary activities depending on the characteristics of reference system elements at an early stage. Through these activities, different purposes could be addressed (see table 1). Important results of this work are the following:

- A systematization of the process for the identification of reference system elements.
- Hints for the work with those reference system elements.
- Examples of effects, that characteristic of reference elements can have on the development process.

These findings can support developers not only in the development of a new product generation itself, but also in the systematic development of the underlying reference system.

6. Outlook

In the next step, systematic literature analysis and case studies are to be carried out in order to describe connections between the findings on RSE and existing description models. The literature will be analysed to find out how known approaches can be adapted to the search for RSE (e.g. approaches such as reverse engineering). In addition, it will be investigated how the findings of the present study can be used to identify more precisely the dependencies on the descriptive models of the PGE and of the system triple. A case study will investigate how the systems engineer can use the reference system to improve the creation of the system of objectives.

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