Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 128 (2024) 555–560

www.elsevier.com/locate/procedia

34th CIRP Design Conference

Future Robust Product Portfolio Development: Modelling Innovation Potentials in Product Portfolios

Michael Schlegel[a]*, Markus Just[a], Felix Pfaff[a], Ingrid Wiederkehr[b], Christian Koldewey[b], Christoph Kempf[a], Roman Dumitrescu[b], Albert Albers[a]

[a]*IPEK – Institute of Product Engineering, Karlsruhe Institute of Technology, Kaiserstr. 10, 76131 Karlsruhe, Germany*

[b]*Advanced Systems Engineering, Heinz Nixdorf Institute, University of Paderborn, Fürstenallee 11, 33102 Paderborn, Germany*

* Corresponding author. Tel.: +49 721 608 45038; *E-mail address:* Michael.Schlegel@kit.edu

Abstract

The advancement of product portfolios is a challenging task for companies. The growing number of variants and a significant increase in interactions between mechatronic products create unprecedented complexities. Currently, there is no holistic approach to cope with this increased complexity and to enable the future robust advancement of the product portfolio.
Therefore, a descriptive model for the advancement of product portfolios is required to map elements of the product portfolio in the early phase of product development. This work aims to build upon an initial descriptive model to support the modelling of innovation potential in the advancement of the product portfolio. This research is based on the Design Research Methodology to develop a descriptive support approach. Challenges and potential improvements were collected while synthesizing the initial descriptive model and an observational study with 29 individual product developers. Based on the descriptive study, product profiles were worked out to describe the higher product portfolio levels solution-openly. As an extension of this feature, common characteristics of different products in the product portfolio can be modeled in a summarized manner. The extended descriptive model was initially validated in an expert workshop with eleven participants.

Keywords: Product Portfolio; Innovation Management; Design: challenges & Innovation;

1. Introduction

One of the core tasks of companies is the advancement of their product portfolio in order to survive in the competitive environment [1]. To understand this process, preliminary work has identified a need for action from theory through a systematic literature review and from practice through an interview Study with seven companies, resulting in five challenge areas [2]. These include product portfolio structure, forces triggering, product portfolio evolution, product portfolio evolution process, and strategies for overcoming these challenges [2]. An ontology was created to show the relationship between central aspects of further development of product portfolios to create a consistent basis [3]. Since no holistic approach for the advancement of product portfolios exists yet, this process must be understood and analyzed. Therefore, a descriptive model is needed that precisely and correctly depicts all relevant aspects [4]. With the help of an interview study, requirements for a descriptive model were defined, and an initial descriptive model was synthesized [5]. This model takes up the structure of a product portfolio and transfers the product portfolio into system generation engineering. In order to identify overarching potentials in the portfolio, and create a basis for further developments, a description of the elements at the respective portfolio levels is required. The description of the elements of the portfolio in the

10.1016/j.procir.2024.03.036

early phase of product development will be addressed in this paper. For this purpose, the necessary basics and the applied Design Research Methodology [6] are introduced.

2. Theoretical Background

This chapter highlights the basics of the initial descriptive model and related preliminary work on which the expansion of the model is based.

2.1. Understanding of innovation and product profile

In order to describe the advancement of innovative product portfolios, the term "innovation" must first be made transparent in the context of this article. An innovation is a technical invention that is successful on the market. As a result, the classification as an innovation can only be concluded with certainty in retrospect after the above-mentioned market success. Since innovations are necessary for a company to be successful in the long term, an increment is needed that shows the possible innovation potential for a system that is under development as early as possible. [7] Albers et al. define innovation as shown in figure 1.

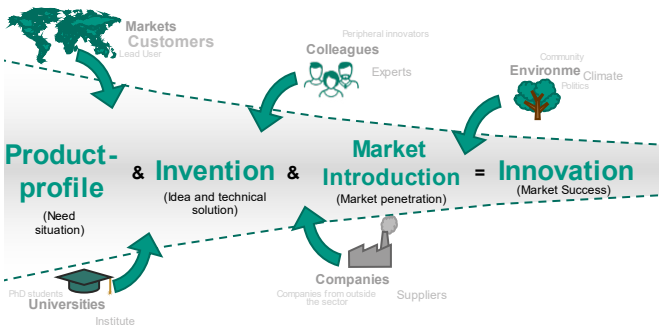

Figure 1: Innovation understanding according to [8]

Based on this understanding of innovation, it can be seen that, in addition to an invention, multiple other factors are at play in creating an innovation. Namely, an initial identification of the need situation, summarized in a largely open-solution product profile, along with a targeted market launch. [8]

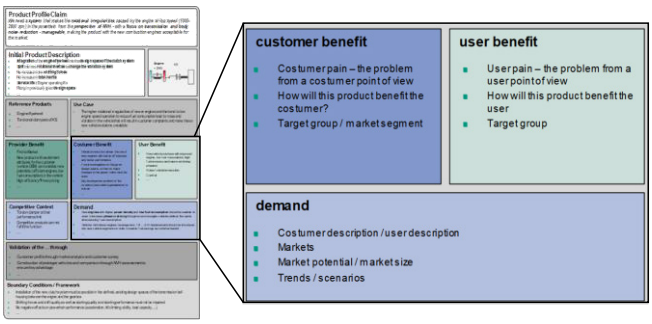

Figure 2: Example product profile dual mass flywheel [9]

In order to avoid undesirable developments, identifying and validatinghe product profile at the beginning of the development is indispensable [9]. At the beginning of development, the benefits to be generated are to be worked out without limiting the solution space by fixating on a concrete form. In the early phase of product development, the product profile shows the bundle of benefits to be addressed and makes this accessible for development [9]. The product profile is further validated during development, and the solution space is narrowed down iteratively and successively [8]. According to Albers, the product profile includes twelve modules, each containing several sub-elements [9]. The product profile is shown in figure 2, using the dual mass flywheel as an example.

2.2. SGE-System generation engineering

The model of SGE - System Generation Engineering according to Albers offers a concept that enables the description of fundamental principles in the development of new products and systems. The model is based on two hypotheses:
1. Every development is based on a reference system, which is composed of elements of already existing or planned socio-technical systems, and represents the basis of the new product generation. 2. A new system generation is developed based on the reference system by a combination of three types of variation: Principle Variation (PV), Attribute Variation (AV), and Carryover Variation (CV). [10]

2.3. Product portfolio structuring

Different approaches already exist for product portfolio structuring. Krause and Gebhardt structure the product portfolio according to the levels product program, production program, product line, product family, and product [11]. In contrast, Fahl et al. specify the three degrees of abstraction as product portfolio, product line, and product variant for structuring [12].Further, Lahtinen et al. even distinguish between a commercial and a technical product portfolio [13].
In order to illustrate the advancement of a product portfolio based on generations, a structure with four levels is administered based on an interview study according to Meyer et al. [4]. The top level is represented by the product lines, which are oriented to the application fields of the respective company. Product lines are divided into product families, which group similar products together. The individual products are described as product variants, which are differentiated according to their value or complexity. Each product variant comprises several components and parts, which are referred to as subsystems. However, a subsystem is not only assigned to one variant but can be used in several variants. [4] This structure of the product portfolio was transferred to the system generation engineering within the framework of the initial descriptive model according to Schlegel et al. and is shown in figure 3 [5].

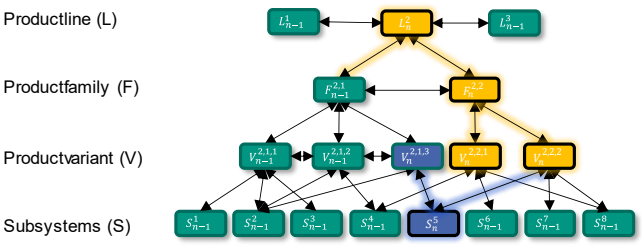

Figure 3: Product portfolio structuring based on four levels with the two description approaches top-down (yellow) and bottom-up (blue) [5]

The product profile is located at the variant level for solution-open description. Two basic description approaches already exist for the description of changes of the elements on the portfolio levels: the top-down and the bottom-up approach. While the top-down approach describes a change that runs from above in the portfolio, the bottom-up approach represents a change that propagates from deeper levels in the portfolio. [5]

2.4. Portfolio development

The advancement of the product portfolio is carried out at the different levels of the portfolio with different task focuses. The specific main tasks are shown in figure 4.

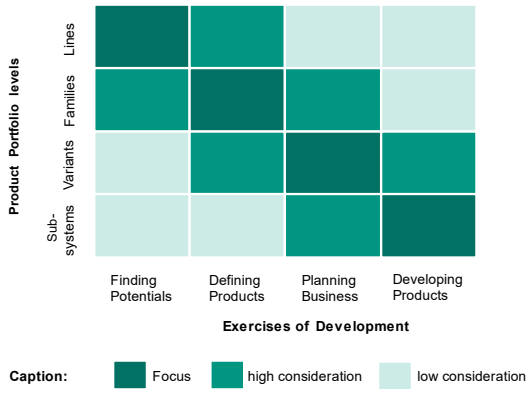

Figure 4: Main tasks at the product portfolio levels [4]

It shows that overarching potentials are identified primarily at the product line level. At this level, only the push for the further development of the product portfolio is specified in the early phase without already having detailed information about the shape of the system. At the family level, the focus is on defining the individual products; here, the characteristics of individual differentiating variants must already be considered. The task of the business planning is settled with emphasis on product variant level since a business model and a business plan must be provided for each variant. Due to this, interactions between individual variants must be considered here. The final specification of the products in terms of product development takes place primarily at the subsystem level. [4]

2.5. Requirements for a descriptive model

At the beginning of the development of a descriptive model, the requirements for the model were worked out to address the central aspects in the multifaceted field of product portfolio generation engineering. As part of a descriptive study, requirements were derived from literature, an interview study with seven experts, and cross-university expert workshops. These requirements were next assessed for relevance in a survey of 32 participants. Fig. 5 shows the most relevant five requirements from the online survey. The result of this relevance assessment shows that the descriptive model should model the mapping of the relationship between the possible elements: product line, family, variant, and subsystem (I1). Furthermore, it should be possible to assign characteristics to individual elements (I5) and to make the effect of a change of a single element on the others visible (I8). It should also be possible to show the interaction of the elements with the user, supplier, and customer benefits (I11). [5]

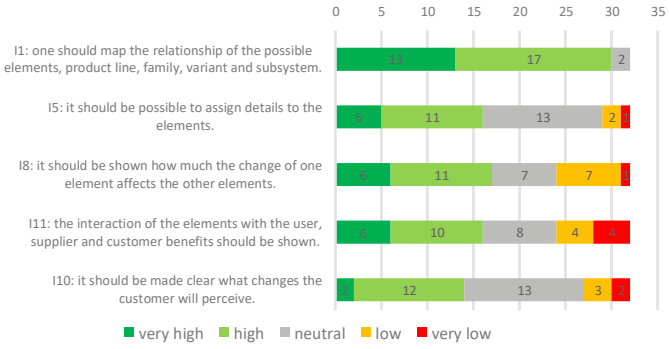

Figure 5: The five most important requirements for a descriptive model [5]

3. Research Design

The descriptive model presented does not yet cover all the necessary requirements. As an example: To address the task emphasis of the portfolio levels, only the product profile on the variant level exists in the current state of research for the solution-open description of the innovation potential. Therefore, the existing descriptive model is to be extended. This is to be investigated (descriptive study I), improved (prescriptive study), and initially validated (descriptive study II) in the following research project based on the Design Research Methodology as shown in figure 6 [6].

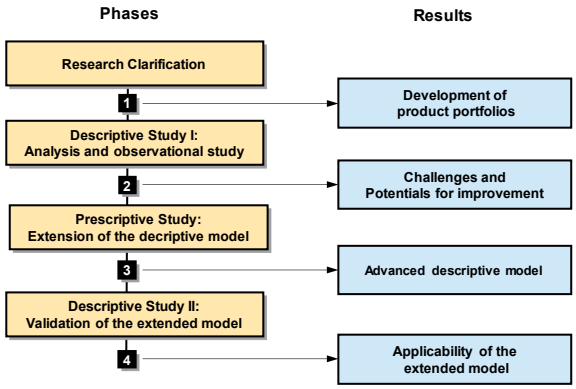

Figure 6: Phases and results of the research project

The descriptive study I deals with the research question: What challenges and potentials for improvement does the existing description model offer for the future-robust advancement of product portfolios? The preliminary work is analyzed in detail to identify the first challenges in the model's scope. This analysis is supplemented by an observational study conducted in the live-lab "ProVIL - Product Development in the Virtual Idea Lab". Here, problems in the application of the model are recorded by observing the various development teams. Considering the descriptive study I, the following prescriptive study answers the research question: How can the existing description model be further developed? Descriptive Study II addresses the following research question: To what extent is the enhanced description model for the advancement of product portfolios applicable, successful, and supportive during implementation? To this end, the enhanced model was applied and initially validated in an expert workshop with eleven experts from the field of development methodology at the Karlsruhe Institute of Technology KIT. The research

environment ProVIL, a live-lab course at the IPEK - Institute for Product Development at the KIT, provides the research environment for the descriptive study of this paper. In the live lab, solutions for a development task of an annually changing company partner are worked out within three months with about 40 developers. The development process includes four phases: Analysis phase, potential identification phase, conception phase and specification phase. [14] For the application of the initial descriptive model in ProVIL, a procedural methodology was introduced, which is divided into four steps carried out in the first two phases of ProVIL. In the first step of the process methodology, the product portfolio is structured. In the second step, product profile analysis, the product profiles are analyzed at the family level. The customer-relevant product characteristics are to be recorded, and in the following step, a consistency analysis of the families' existing product profiles is to be carried out. Finally, an analysis of concrete product ideas is carried out at the variant level. [5]

4. Research and Results

In this chapter, the potential improvements as a result of the Descriptive Study I (DS I) are presented. Based on the potential improvements, the extensions to the initial descriptive model, as shown in chapter 2.3, are presented (PS) and subsequently validated in an expert workshop (DS II).

4.1. Descriptive Study I

Potential improvements during the synthesis of the initial descriptive model are collected, along with the conduction of interviews with the developers of ProVIL to analyze the presentations of the results. The following table summarizes the potential improvements found in DS I.

Table 1: Challenges and potentials for improvement of the initial model

	Potential improvements	Source
P1	Specify the two description approaches to include the specific effects of changing super-elements on sub-elements and vice versa.	Synthesis [5]
P2	Extension of the product profile at the family level, for example, to include regularities for variant generation	Synthesis [5]
P3	Extension of the product profile to the subsystem level to concretize the solution	Synthesis [5]
P4	Strategic input is currently not yet taken into account in the process methodology	observational study ProVIL
P5	The analysis results in ProVIL were hardly used in the later phases	observational study ProVIL

The requirements I5 and I11 for the descriptive model presented in chapter 2 show that a solution-open description should be possible at the higher portfolio levels, considering the customer, user, and supplier and containing further details. Looking at the result of structuring the product portfolio from ProVIL from this point of view (see figure 7), the product portfolio is very complex. It confirms that a description at the higher portfolio levels is needed to make the complexity manageable. With the help of such a description, it is also possible to address the focal tasks at the product portfolio levels because increments at the higher levels are currently missing. Based on these findings, the potential improvement P2 of extending the product profile to the higher portfolio levels is prioritized.

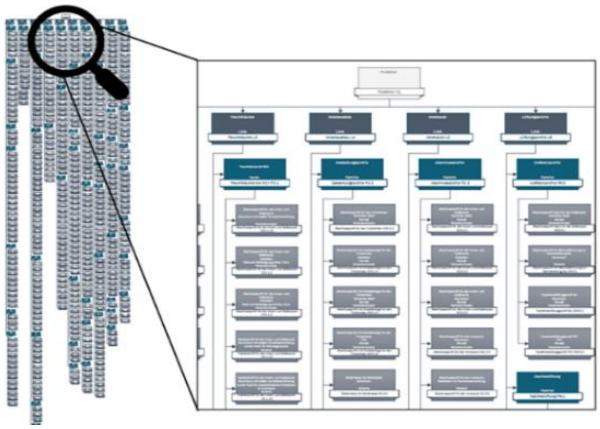

Figure 7: Result of ProVIL's portfolio structuring (white: product portfolio, dark gray: product line, blue: product family, light gray: variant) [5]

4.2. Prescriptive Study

In the prescriptive study, solution-open description profiles are created for the portfolio elements at the higher portfolio levels based on the product profile. Based on the understanding of innovation according to Albers et al., the four module groups of benefits, product structure, stakeholders, and environmental development are to be addressed in the profiles. Based on the product profile and the requirement (I11, section 2.1), the module groups of benefits and stakeholders will be examined from the customer, user, and supplier perspectives. The environmental development module group is divided into economic, technological, and socially, with socially consisting of ecological and social [15]. Each of these module groups comprises modules and sub-elements depending on the level. The company's strategy significantly influences the product portfolio[16]. This interface between strategy and product portfolio is to be represented via a company profile. Overarching information is included in this company profile. The core benefits, strategy, and core competencies, the customer, user, and supplier base, as well as the industries in which the company is active, are addressed. To provide an interface for the advancement of product portfolios, the company profile integrates key factors from the industries in the sense of the scenario method from foresight.

Based on the relation that information about the product at the variant level is already determined at higher portfolio levels, it follows that specific information from each module group can be inherited in the profile of the level below. In the product line profile, the relevant information of the sub-elements for the family profile is specified and inherited. For example, in the benefits module group, part of the core benefits sub-element is inherited from the company profile and specified around the application field benefits. Properties are defined, and the customer, user, and supplier base can be narrowed down. The markets that are served in the respective industries are listed, and characteristics for the key factors can be specified. This inheritance of information is indicated in the product family profile shown in figure 8., which in turn inherits and specifies information from the company and product line profiles. The

inherited information is specified via "[relation]:" in the sub-element, and intervals are specified in the product family profile where the underlying variants are located. This inheritance is intended to help the developer describe the product profiles more efficiently and consistently.

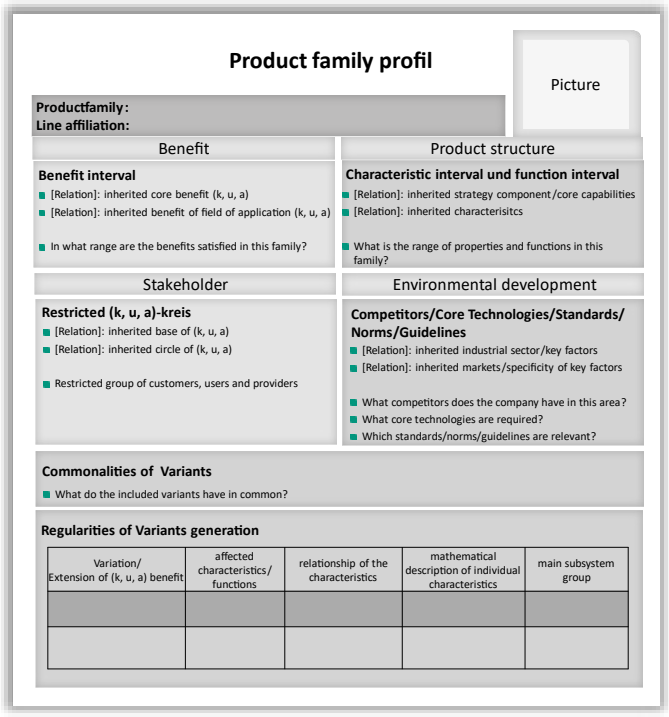

Figure 8: Product family profile

The idea of inheriting information across product portfolio levels can be compactly summarized in a "product DNA" containing information from the individual profiles. As can be seen from the product DNA in figure 9, the profiles consistently merge into the already established product profile at the variant level.

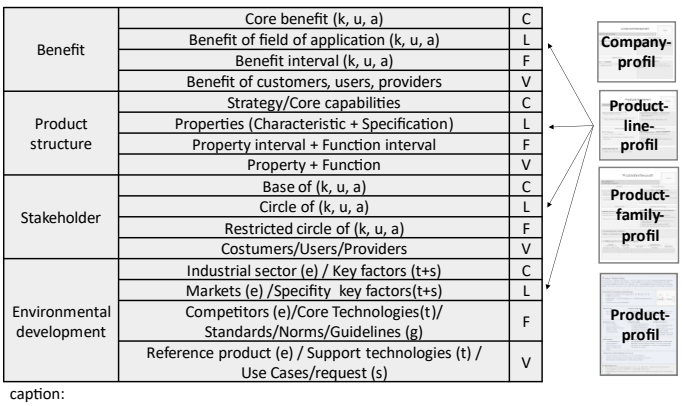

Figure 9: Product-DNA

Under the introduced term of the product DNA, which arose in reference to computer science and biology, the bundling of core information of a product is understood. A transfer of all interactions connected with the term DNA in other areas is not intended. Furthermore, the inheritance addressed in the profiles is to be seen spatially in the sense of the various levels and elements in the product portfolio. It is distinctly separate from a temporal view. The temporal development of inheritance has to be investigated in further research projects, starting from the variant level.

4.3. Descriptive Study II

In Descriptive Study II, initial validation was carried out through an expert workshop. The 11 participants were asked to transfer the profiles to a company. Table 2 shows the results of the validation by the expert panel.

Table 2: Statements from the expert workshop discussion panel

	Notes
C1	Inheritance is generally applicable and can be integrated into the profiles
C2	Specific knowledge about a company is needed to fill in the product profiles
C3	The further development of the profiles must be based on a reference system at each level
C4	The profiles are to be embedded in a kind of "user manual"
C5	Integrate locations into the company profile
C6	The Five-Forces Model, according to Porter

The initial validation showed that inheritance is generally applicable and can also be integrated into the profiles (C1, Chapter 4.3). However, very specific knowledge about a company is required, making validation using retrospective case studies difficult. (C2, Chapter 4.3). Prerequisites were discussed, which must be considered for further development with the help of the profiles. Thus, the advancement of the profiles is based on a reference system at each level (C3, chapter 4.3), where the sub-elements are transferred to the reference system (chapter 2.2). For this purpose, a first approach has already been created, as shown below. Figure 10 shows that development in generations at the different levels takes place over different periods of time. This is represented by the planning horizon and visualizes that at higher portfolio levels. A longer period is envisaged for a new generation, as shown in the following figure.

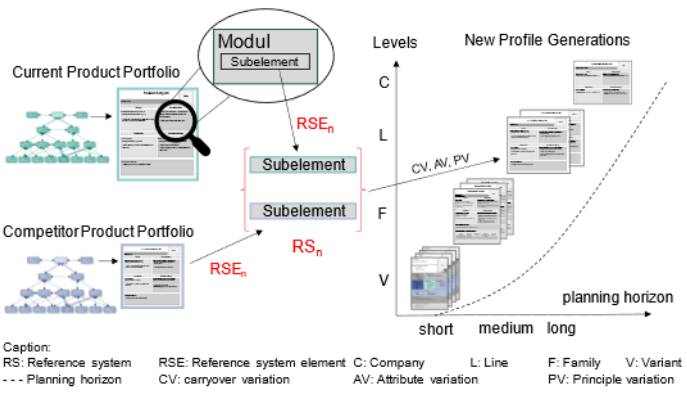

Figure 10: Reference system approach figure cf. [16]

For advancement with the help of the profiles, these are to be embedded in a kind of "instruction manual" (C4, chapter 4.3), which indicates the level of detail. Another point was suggestions for extensions, such as integrating locations into the company profile (C5, chapter 4.3) or taking Porter's five forces model [17] into account (C6, chapter 4.3).

5. Discussion

The research study thus shows a first approach to how innovation potential can be modelled in the early stage and at different levels of the product portfolio. For the increasing number of products in companies and increasingly complex systems, the approach represents a basis for modelling innovation potential, making the complexity that arises manageable by modelling multiple product variants in one product family profile. The level-specific orientation of the profiles also addresses the associated key activities, as correlating information for specific activities is provided. This allows suitable methods and processes to be developed based on the modelled product profiles, which support the advancement of product portfolios.

6. Conclusion and Outlook

The advancement of the product portfolio represents a core task for companies in order to be able to survive in competition [4]. In this context, the products must be seen in the light of product portfolios and must not be viewed in isolation. Currently, there is not yet a model that fully represents the advancement of product portfolios [2].

An initial descriptive model was synthesized by the authors in a previous study and extended further throughout this work. The descriptive model requirements and the results from ProVIL and portfolio development indicate that a description of the elements at the higher portfolio levels is needed.

In the Descriptive Study I, challenges and potential improvements of the initial descriptive model were collected. Due to the need for research, expanding the product profile to the higher portfolio levels was prioritized.

In the Prescriptive Study, a company profile, product line profile, and product family profile were introduced. Four main module groups (benefit, product structure, stakeholders, and environmental development) are addressed in the product profiles, which contain further modules and sub-elements depending on the level. Each sublevel inherits information from the corresponding superlevel from the sub-elements of the profile and specifies them. Core information from the respective levels can be bundled into a product-DNA.

The profiles were applied to a company for initial validation and discussed in an expert workshop in descriptive study II. In principle, the profiles could be applied, and inheritance across levels could also be performed. Extension possibilities were suggested, and prerequisites for applying the profiles in advancement of product portfolios were discussed. In principle, the profiles make it possible to describe the elements at the upper portfolio levels solution-openly in the early phase of product development.

In further research projects, the profiles are to be comprehensively validated. A comprehensive study will be conducted in which the modelling approach is applied in a company to determine benefits and identify further challenges. In a follow-up project, the profiles can be used in a web-based application. When creating a profile, it should be able to display references to the superordinate levels.

Acknowledgements

The authors gratefully acknowledge the support from the German Research Foundation (DFG): “Future Robust Product Development: Systematic Extension of the Model of PGE – Product Generation Engineering by Adaptation of the Methods of Strategic Product Planning - 437943992”

References

[1] Cooper, R., Edgett, S., 1999. Portfolio management for new products, in: Smart, W.B., Smart, D.T. (Eds.), Over The Rim. Utah State University Press, pp. 191–199.
[2] Schlegel, M., Wiederkehr, I., Rapp, S., Koldewey, C., Albers, A., Dumitrescu, R. Future-robust evolution of product portfolios: Need for action from theory and practice. 56th CIRP Conference on Manufacturing Systems, CIRP CMS ‘23, South Africa.
[3] Schlegel, M., Wiederkehr, I., Rapp, S., Koldewey, C., Albers, A., Roman, D., 2023. Ontology for Future-robust Product Portfolio Evolution: A Basis for the Development of Models and Methods. 33rd CIRP Design Conference 2023.
[4] Meyer, M., Tröster, P.M., Hemkentokrax, J.-P., Schlegel, M., Kling, C., Koldewey, C., Rapp, S., Dumitrescu, R., Albers, A., 2021. Zukunftsrobuste Weiterentwicklung von Produktportfolios: Erkenntnisse und Handlungsbedarfe aus der Praxis. Symposium für Vorausschau und Technologieplanung Berlin 2022.
[5] Schlegel, M., Wiederkehr, I., Rapp, S., Koldewey, C., Albers, A., Dumitrescu, R., 2023. Design of a Descriptive Model for Product Portfolio Evolution Based on the Model of SGE – System Generation Engineering. R&D Management Conference, Seville Spain, Responsible and Responsive Innovation for a Better Future.
[6] Blessing, Chakrabarti (Eds.), 2009. DRM, a design research methodology. Springer, Dordrecht, London, 397 pp.
[7] Schumpeter, J.A., 1934. The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle. Harvard University Press, Cambridge, Mass., 255 pp.
[8] Albers, A., Heimicke, J., Hirschter, T., Richter, T.O., Bursac, N., 2018. Managing Systems of Objectives in the agile Development of Mechatronic Systems by ASD – Agile Systems Design. NordDesign.
[9] Albers, A., Heimicke, J., Walter, B., Basedow, G.N., Reiß, N., Heitger, N., Ott, S., Bursac, N., 2018. Product Profiles: Modelling customer benefits as a foundation to bring inventions to innovations. 28th CIRP Design Conference, Nantes, France Nantes, France 70.
[10] Albers, A., Rapp, S., 2022. Model of SGE: System Generation Engineering as Basis for Structured Planning and Management of Development, in: Krause, D., Heyden, E. (Eds.), Design Methodology for Future Products. Data Driven, Agile and Flexible, 1st ed. 2022 ed. Springer International Publishing; Imprint Springer, Cham, pp. 27–46.
[11] Krause, D., Gebhardt, N., 2018. Methodische Entwicklung modularer Produktfamilien. Springer Berlin Heidelberg, Berlin, Heidelberg.
[12] Fahl, J., Hirschter, T., Kamp, J., Endl, M., Albers, A., 2019. Functional Concepts in the model of PGE - Product Generation Engineering by the Example of Automotive Product Development, in: Proceedings of 5th International Symposium on Systems Engineering (ISSE) 2019. 2019 IEEE International Symposium on Systems Engineering (ISSE), Edinburgh, UK. 01.-03.10.2019. IEEE, Piscataway, NJ, USA, n. p.
[13] Lahtinen, N., Mustonen, E., Harkonen, J., 2021. Commercial and Technical Productization for Fact-Based Product Portfolio Management over Lifecycle. IEEE Transactions on Engineering Management 68 (6).
[14] Albers, A., Bursac, N., Walter, B., Hahn, C., Schröter, J. ProVIL-Produktentwicklung im virtuellen Ideenlabor. Stuttgarter Symposium für Produktentwicklung 2017.
[15] Müller, A.W. Strategic Foresight : Prozesse strategischer Trend- und Zukunftsforschung in Unternehmen, Universität St.Gallen.
[16] Albers, A., Rapp, S., Spadinger, M., Richter, T., Birk, C., Marthaler, F., Heimicke, J., Kurtz, V., Wessels, H., 2019. The Reference System in the Model of PGE, in: Proceedings of the 22nd International Conference on Engineering Design (ICED19), Delft, The Netherlands, 5-8 August 2019. 2019. Delft.
[17] Porter, M.E., 2008. The five competitive forces that shape strategy. Harvard Business Review 86 (1), 25–40.