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Product Family Models and Knowledge Transfer Support for the Development of Modular Product Families

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Abstract
Developing modular product families meeting market demands and optimized to company processes requires extensive knowledge from many departments that needs to be communicated using product representations. In this paper, findings from applications of a product family development method are presented and possibilities for improvements through advanced product family models and methodical knowledge transfer support are identified.

Keywords: Product Family Development, Product Models, Knowledge Transfer.

Introduction

Companies are facing more and more diverse customer demands and the resulting differentiation leads to the risk of high variety of parts and processes. Modular product family development has the potential to reduce this internal variety. However, successful product family strategies must not only meet the marked demands, but also have to be adapted to the company structure and processes [1]. Gathering relevant information, establishing visualisations and analysing the product makes up a major part of the necessary work. Acquiring the necessary level of knowledge in this matter requires product representation and communication processes that foster the information exchange between the engaged designers and other departments.

The aim of this paper is to find needs and potentials of how the development of modular product families can be improved by using information and knowledge transfer and a common product family model. Especially, an easier integration of approaches into companies and their product development process is sought for. It will be discussed, to the which extend this integration could be supported by advancing the understanding of modular product families, easing the effort of gathering information, better visualization, communication, decision-making and documentation.

For this purpose the following steps are presented.

- A review of the related literature on modular product family development approaches, knowledge management and product models in product family development.
- An analysis of the integrated PKT-approach developed at the Institute for Product Development and Engineering Design (PKT) with a focus on required and exchanged knowledge, as well as the use of models for product families.
- An outlook for possible support by knowledge transfer and product family models.

This work and the analysis are based on experiences from industrial cases in which the integrated PKT-approach was applied. The approach is considered here as an example for a multi-product development method; similarities with other existing approaches will be presented to allow some generalisation of the findings.

State of the Art

As a background for later analysis on possible improvement potentials by knowledge transfer and product family models, this chapter will present selected approaches of modular product family development and their context to the integrated PKT-approach as well as general fundamentals of knowledge and information management and product modelling.

Development of modular product families

Mortensen et al. [1] propose a method that encompasses the development of market, product and production concepts to align the structure elements among them. The method utilizes the idea of visual product modelling and distinguishes different views on relevant product data, but so far concentrates on paper-based applications. Therefore, working in interdisciplinary team sessions is the focus within the approach [2]. Jiao et al. [3] presented an approach for developing a Product Family Architecture (PFA) that utilizes three similar views on product family design. In the functional view, customer requirements are structured to derive the overall demand on the product family. They are mapped to design parameters of the technical view and modules are derived. In the physical view, modules are evaluated regarding their alignment with companies' processes, production costs and customer value. Jiao et al. use automatic algorithms for structuring and point out the need for applying view or domain specific knowledge. Further specialised approaches are described in literature; e. g. the matrix-based structural complexity management by Lindemann [4], modularization method based on strategic module drivers by Erixon [5] or methods for developing variant products e.g. Franke et al. [6]. A detailed review of methods can be found in [7].

Integrated PKT-approach for developing modular product families

The approach was developed at the Institute for Product Development and Engineering Design (PKT) and aims to generate the required external product variety by using the lowest possible internal process and component variety [8]. In this work method units "design for variety" and "life phases modularization" are considered due to their role as the core steps within the approach and their maturity. Further method units of the approach are currently under development and are shown in Figure 1 likewise.

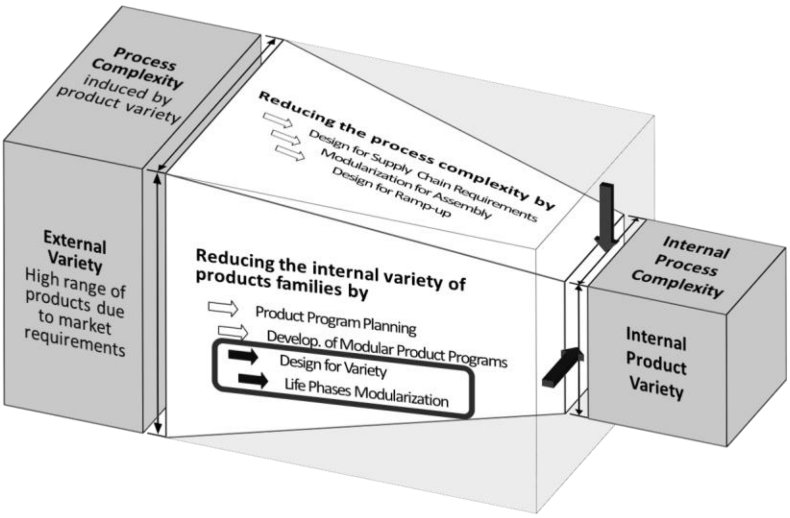

Figure 1 Integrated PKT-Approach with scope of this work marked

By the methodical unit Design for Variety [9] the variant product properties on the market are mapped to variant functions, working principles and components and the resulting product family structure is analysed (Figure 3). An improved product family structure is derived using a theoretically ideal structure of variety-oriented product families. Following this, individual modularization concepts for each relevant life phase are established using enhanced module drivers [10]. These concepts are merged into an overall module concept based on the idea that the modularization of a product can purposely be changed from one life phase to another – thus modularization needs are better served.

Findings in this paper will be based on a process analysis and industrial applications of the integrated PKT-approach. For the purpose of generalization, Figure 3 shows a comparison of an exemplary set of methods for the development of modular product families.

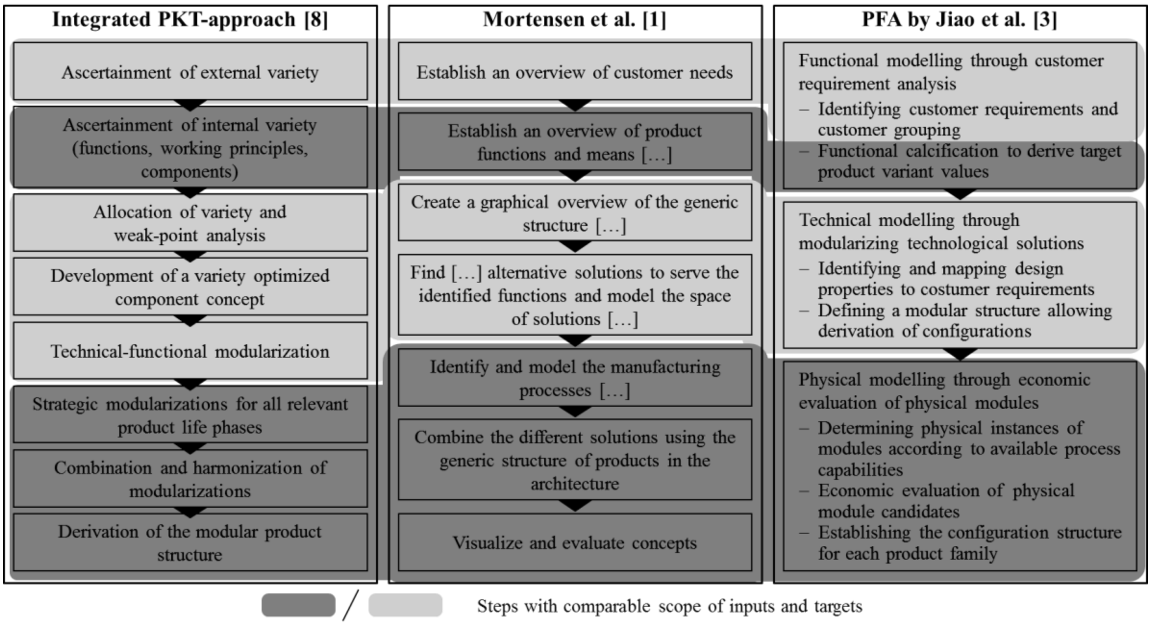

Figure 2 Set of exemplary methods for the development of modular product families

Information and knowledge management

According to Probst [11] data put into context forms information and information linked for a specific purpose is knowledge. Knowledge is the sum of expertise and skills that individuals use for problem solving and thus bound to persons. Information is the medium that is used to communicate and store knowledge. Explicit knowledge is easy to articulate and can be stored in data bases as information or communicated to others. On the other hand tacit knowledge cannot be articulated and subsequently cannot be stored or directly communicated, but is of high relevance while developing innovative products [12]. For this reason, the analysis of product family development needs to consider both knowledge and information.

Knowledge management aims to use and manage knowledge to improve the competitive edge of the company in a holistic way. Nonaka and Takeuschi [13] describe how the company learns through the transfer of tacit knowledge to explicit knowledge, and the spreading of existing knowledge from individuals to larger groups. While knowledge management focuses on the holistic management of knowledge, information management focuses on information handling using IT structures. Product Data Management (PDM) systems manage data of all product life phases, provide user-specific outputs and allow handling of product variants [14].

Common knowledge and information management approaches do not suite the specific demands of methodical product family development enough. However, adapted knowledge management may support knowledge transfer in product family development. Information management can serve as an interface between general product-related data and the development process for product families.

Product models

Analogous to general definitions of models in science, product models are seen as simplified, abstract representations of products, their properties and behaviour [2], [16]. They allow users to improve their understanding of the product, to analyse its structure and behaviour, and to develop and improve it [17]. Evidently the setup of a product model has a significant impact on the development process. Shape and detail of the models need to be specific to the objectives, roles and the prevailing tasks of users [19]. Especially by PDM systems, this user specific adaption is carried out using product model views, displaying the reduced product information. In contrast to this, partial product models only contain a certain class of product attributes and their relations, e.g. a function structure or a requirements list. Partial models do not share information, whereas different model views may do so and combine one or more partial models. Both principles help to reduce and individualize the product data for a case-specific representation of the product [18], [20].

For the purpose of handling variety, many PDM systems use abstract components acting as placeholders in the description of the product structure combined with configuration rules [16]. Similar approaches can be found within the Product Family Architecture [3] or in the Product Family Master Plan [21]. Depending on content and purpose models may consist of views, diagrams, objects or processes [19]. In engineering work, a visual modelling approach supports the designer in solution finding and communication of concepts [22], especially if the displayed elements show similarity to real product geometries [1].

Analysis of the methodical process and findings from industrial cases

To identify improvement potentials of existing development approaches, an analysis of the integrated PKT-Approach was conducted. Browning [23] provides different modelling approaches for development processes. In this work an adapted process modelling that concentrates on the visualisation of information flows was used to reveal required and generated knowledge and the applied product family models.

Figure 3 gives an insight into the results, showing for instance significant knowledge demand about products and methods that need be supplied by the R&D department.

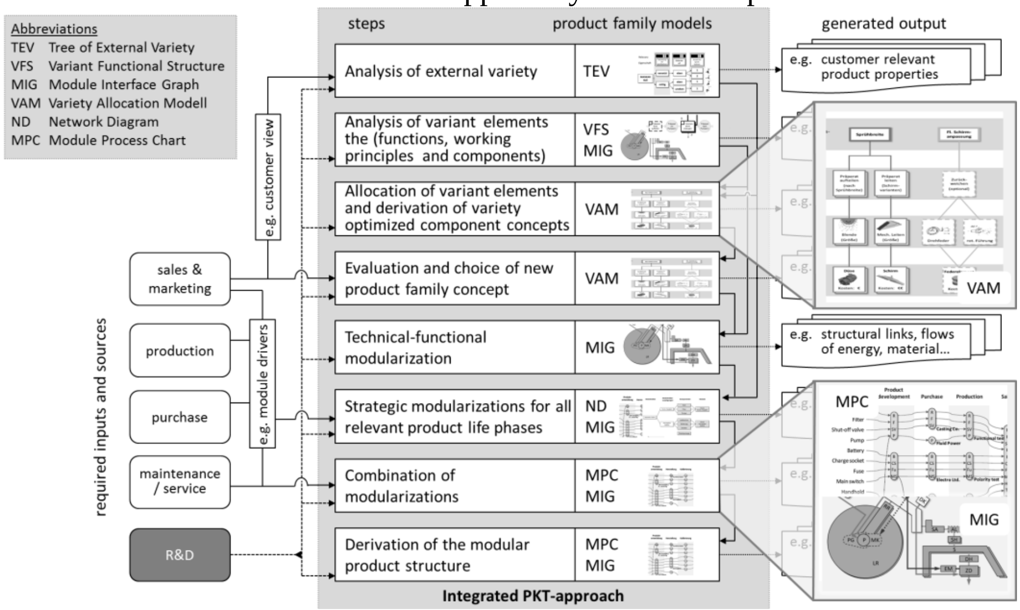

Figure 3 Simplified visualization of product family models and knowledge transfer analysis

Especially in defining and aligning modularizations, information and knowledge flows show multidisciplinary character of the process. In the following the step "analysis of the external variety" will be explained as an example. Information about the customer view of the product

(required input) is needed here, which can be provided by sales and marketing department (source) and then incorporated into the Tree of External Variety (TEV, product family model). The TEV provides transparency about the customer relevant product properties (generated output knowledge).
Industrial cases were analysed as well summarized in Table 1. The case studies are discussed in more detail in [24], [9] and [10]. Critical findings from process analysis and case studies with high methodical relevance will be presented in the following sections.

Table 1 Industrial cases analysed for improvement potentials [24]

Products	Company size	Case characteristics	Study focus
1 Herbicide spraying systems	small (<100)	middle-sized product family	initial evaluation
2 Immersion pumps	large (>10000)	middle-sized product family	
3 Ground conveyor	large (>10000)	large-sized products, broad product range	evaluation of boundary conditions
4 Gas detection device	large (>10000)	concept phase of redevelopment	
5 Paper converting machines	medium	large sized product in new development	
6 Displays	large (>10000)	components, electrical products	evaluation of usefulness and usability
7 Operating device	large (>10000)	components, electrical products	
8 Fork carriage	large (>10000)	components, connection to simulation	
9 Gas inlet valves	medium	small-sized product family, embodiment design	
10 Measurement systems	large (>10000)	electrical products, product planning	

Necessary methodical knowledge and skills
Even in industrial cases with highly variant products special methodical knowledge and skills how to reduce internal variety was rarely present in the company. Designers tackle the challenge mostly without any particular methods or processes. Sometimes basic knowledge about the phenomenon of modular product family structures is lacking as well, which makes clarification of specific goals and relevant product components difficult. Efficient training for designers and staff involved is very important and in need of improvement.

Information acquisition and necessary preparation
Improving product family structures requires a high amount of information in an initial product analysis. Lacking interfaces to PDM systems and resulting work effort often hamper an integration of methods into development processes. E.g. acquiring the planed external variety could be simplified by adapted marketing documentation guideline that provides a common information format. The TEV represents a product family's external variety by variant product properties, their specifications and combinability from the customer perspective. Marketing works with different terms and tools, making translation of information necessary.

Using existing company knowledge and preservation of project knowledge
The rapid and sufficient identification of relevant knowledge sources in the company is a challenging task. The project team often lacks knowledge of information sources (e.g. data bases of other departments) and of experts in specific aspects of the product family development. This makes it challenging to involve the right people and subsequently the right (tacit) knowledge. The task of life phase specific modularization asks for the integration of many company departments. Choosing the right stake holders is of special importance. Often large effort is put into creating knowledge and transparency (e.g. external variety) within a development project, which is not reused in the company.

Product understanding, views and visualization
A fundamental issue about applicability and usability of methodical approaches to product family design seems to be the underlying understanding of the product family. Models used in these approaches are often not comparable to the product understanding designers have. Thinking in functions and working principles proved to be too inappropriate in problem solving tasks in companies. This has impact on product data acquisition, analysis, design

improvement as well as implementation of concepts. E.g. function structures are rarely available and product concepts formulated in terms not used in a company will be difficult to communicate. Reports from application in the industry often showed that the Variety Allocation Model (VAM) as a tool for solution finding was rarely used for this purpose but only in variety analysis. The VAM can be enhanced by visual links to the real product setup resulting in easier understanding, communication and solution finding. Another critical aspect is the description of the product variety in the market. Working on current product technologies, designers in engineering companies often think in very technical parameters. The phrasing however needs to represents the customer's point of view to derive customer relevant functionality and variety. In general product models have to support communication, and mediate and translate between people with different background within a company.

Analysis and improvement of the product variety

The step after establishing a thorough understanding of the planed external variety is the analysis of the internal variety. Product development processes should allow problem based adaption to keep workloads appropriate. E analysing the product variety in the VAM often showed high efforts in comparison to the derived product knowledge necessary in later steps. When modelling the external variety a clear differentiation should be made for different kinds of variety drivers (e.g. customers' individual needs, country specific regulations etc.). It is equally appropriate to take impacts of component variety on the processes into account, too. A well-handled component variety that serves an important customer individual property of the product should be well distinguished from inefficient variety.

Product family modularization

When establishing the modularization concepts for different life phases specialized methods that derive the optimal concepts for each view can be helpful. Such methodical approaches can partly be found in the literature and are currently under development within the integrated PKT-approach. Utilizing existing product data sources in companies (such as requirements for instance) and individual modularization models seems to be promising.

While aligning the modular structure of the new product generation to the requirements of the life phases it was observed that existing process structures and organizations were taken into account. For example, the module structure is aligned to the needs of the purchase departments only taking existing suppliers into account. Strategic objectives of the company like core competencies (favourable in house production or outsourcing of the components) are not consider methodically. To improve this issue the product family development could be seen as a general structuring process that requires the participation of strategic management.

The PKT-approaches aligns different life phase specific modularizations in a module process visualized by the Module Process Chart (MPC). By this the newly defined module process may vary from current company process which subsequently may have to be adapted. This requires currently not methodically supported communication of the project results and concepts to affected departments. Simultaneous development of processes and product family can offer possible improvement potentials. The decision which life phases are relevant and their priorities in concept conflicts are so far not supported enough. Decisions in aligning the modularization could have an extensive impact in different life phases. Estimating this impact is complex due to a lack of experience of the impacts of such decisions in the past.

Future research needs for knowledge transfer and product family models

Current development and research needs for the integrated PKT-approach were derived by process analysis and industrial case studies concerning knowledge transfer and product family models summarized below. Other current research projects on the integrated PKT-approach can be found in [8], [24].

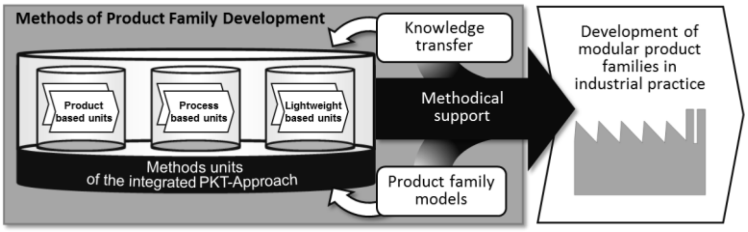

Figure 4 Improved methodical support by knowledge transfer and product family models

Concerning suitable modular product family models following central needs could be elaborated. The underlying structuring principle should conform to common industrial practice. Modelling needs to be visual providing linkage to product shapes for better understanding and concept communication. Modelling principles should foster the currently insufficient understanding of benefits available from modular product families. Handling variety in visual product family models can be improved. Clear differentiation should be made for different variety drivers and impacts on components and process variety. Partial models and views should follow certain common structures in order to allow recognition of modelling principles. Product family models and development methods should allow project specific adaption of the analysis depth in order to adjust work load. Concepts need to be made how to connect and integrate the tools and methods into local PDM and development processes. The models should be usable for departments elaborating the concepts after product structuring.

Knowledge from many stake holders is needed to develop a modular product family. The information acquisition effort is high due to missing integration of methods into companies' development process and the absence of information interfaces. Creating such interfaces and processes could increase the acceptance of methodical product family development in industry. Such support needs to be able to help identifying relevant stake holders and to support the filtering ad preparation of relevant knowledge. Defined interface are also needed between different specialized methods (e.g. in life phases modularization) to allow the creation of a holistic product family method that can be adapted to specific companies' needs.

To foster the success of new modular product family concepts, they need to be communicated to the different company departments in order to achieve an alignment of product and process concepts. Knowledge transfer can provide interfaces and processes to allow the active use of project knowledge in the implementing departments. Furthermore, easy access to project information reduces redundant work.

Conclusion

The analysis of the integrated PKT-approach for developing modular product families has shown the potential for further improving its usability and usefulness in industry by advanced product family models, knowledge transfer support and information interfaces. Aim of resulting future research is to consolidate the existing methods.

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