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An Approach for reducing Variety across Product Families

Sandra Eilmus and Dieter Krause
Institute of Product Development and Mechanical Engineering Design (PKT)
Hamburg University of Technology (TUHH), Germany
sandra.eilmus@tuhh.de

Abstract
Reducing internal variety in a company needs to move beyond the focus of development of product families, as industrial case studies have shown. To systematically achieve this, a methodical approach is needed to support product designers. Steps and tools from methods for product program planning and product family design as well as basic ideas of modularity, commonality and platform thinking are integrated into an approach for the Development of Modular Product Programs.

Keywords: Product Family, Product Program, Modularity, Platform, Commonality

Introduction

The potential to reduce internal variety in a company cannot only be exploited by developing modular product families but even by aligning a modular strategy across product families. However, methodical approaches that support engineering designers in managing, aligning and performing this complex task are rarely described. The aim of this contribution is to describe this task and its challenges and to present the first steps towards methodical support. While evaluating the Integrated PKT-Approach for Developing Modular Product Families [1, 2] (Figure 1) using industrial case studies, the need for research was defined and analysed, as described in the following. Based on the industrial experience, literature was reviewed that might contribute to the task, particularly in the fields of product programs and product families as well as modularity, product platforms and commonality. The findings of the literature review are integrated into a methodical approach presented subsequently.

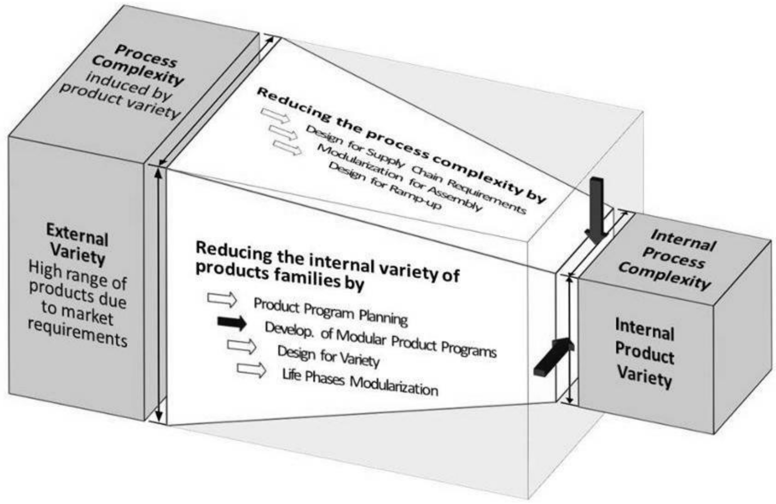


Figure 1 The Integrated PKT-Approach for Developing Modular Product Families

The Integrated PKT-Approach for Developing Modular Product Families

The integrated PKT-approach [1] aims to reduce internal variety with the help of several methodical units that can be combined to offer tailored methodical support to a specific corporate situation. The methodical units of Design for Variety and Life Phase Modularization [3] have been evaluated in previous research activities [2] to define need for further research. They include the following steps and tools (Figure 2):

1. Analysis of external variety using the tree of variety
2. Analysis of variant functions generating a product family function structure
3. Analysis of variant components drawing the Module Interface Graph (MIG)
4. Analysis of variant working principles
5. Derivation of optimized component concepts using the Variety Allocation Model (VAM)
6. Evaluation and choice of new product family concept
7. Identification of life phases-specific module drivers
8. Modularization over all life phases using the Module Process Chart (MPC).

The development of a methodical unit for the Development of Modular Product Programs is addressed in this paper. It partly refers to on-going research to develop a methodical unit for Product Program Planning [4], which is referred to below.

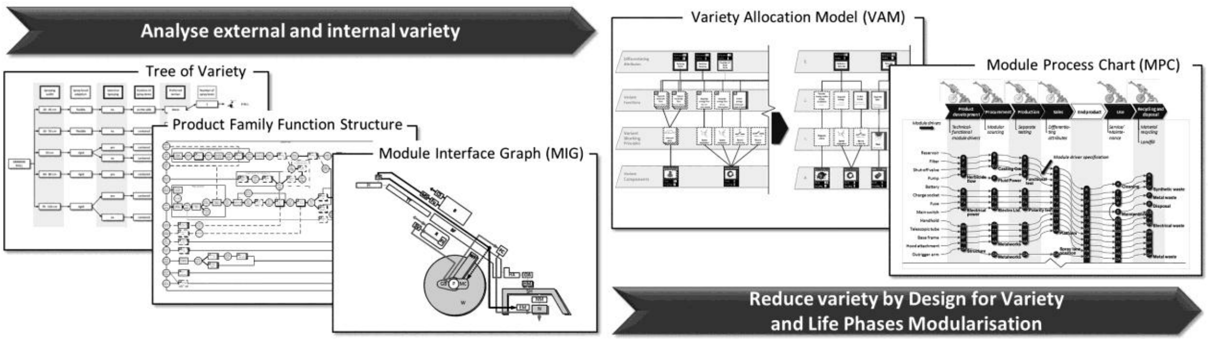


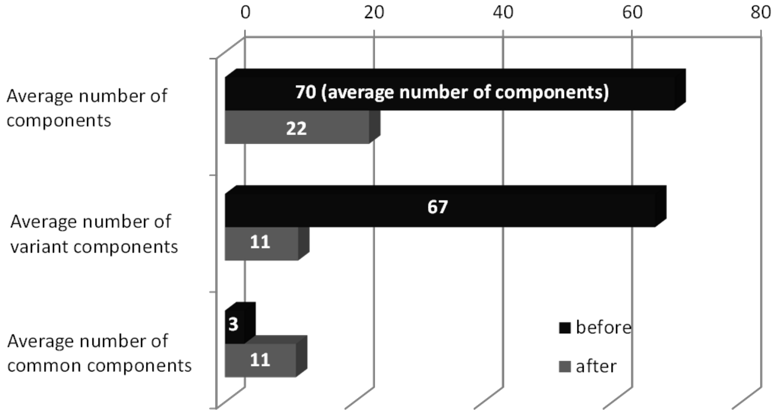
Figure 2 Tools of Design for Variety and Life Phase Modularization [3]

Identification of potential and needs through industrial case studies

The potential to reduce internal variety was analysed using ten industrial case studies [2]. The original aim of these case studies was to evaluate the integrated PKT-approach. The original scope of product families was expanded during the case studies to react to the corporate needs of the industrial partners involved, as they wanted to exploit the potential of reduced internal variety across product families by applying the integrated PKT-approach to several product families or to individual modules being used across several product families. The results of these case studies showed that important reductions in internal variety can be achieved in this way. For example, the number of module variants to handle was reduced from 15 to 4 in the control devices of industrial trucks. The modules are made from 17 components in total, instead of the previous 82. A summary of the results is shown in Figure 3. Using the integrated PKT-approach that was originally meant to be used with a product family focus in these studies, an understanding of the specific challenges of this new task could be reached. One challenge is how to identify appropriate design tasks that would lead to variety reduction. To do this, the whole product program needs to be analysed systematically. Another challenge is the complexity of the task. Activities within and across organizational units need to be aligned. Compared to the development of product families, the products of a product program provide a broader range of external variety based on a broader range of internal variety. There are more technical constraints connected to components used over the whole product program compared to those only used within single product families. This is why aiming at mere standardisation potential can only be found in small parts in most product programs.

These conclusions lead to a refined research task:

- Support the systematic analysis of variety over the whole product program.
- Handle the extra complexity of the task, for example, by:
  - Aligning and managing the efforts within and across product families.
  - Showing ways of reducing variety even if the claimed external variety and technical constraints of the products forbid mere standardisation.



Project	Components overall before	Components overall after	Variant components before	Variant components after	Common components before	Common components after
Control device	83	17	82	12	1	5
Operating device	73	28	71	13	2	15
Gas inlet valves	53	22	47	9	6	13

Figure 3 Results derived by applying the integrated PKT-approach across product families [2]

Related research and its contribution to the task

The systematic development of variety-optimized product programs is rarely discussed in literature. Research fields that might yet contribute to the task are presented below.

Development of product programs

Literature dealing with the development of product programs mainly concentrates on strategic product program planning, as summarized in [4]. The research project Product Program Planning by Jonas [4] aims to enhance this planning at a product structure level, while taking into account the lowest possible internal variety by offering appropriate external variety. This methodical unit of the integrated PKT-approach leads to future scenarios and carryover candidates i.e. components with high reuse potential across product families. These carryover candidates are identified by analysing similarities in the customer-required differentiating product properties of the variants. The analysis of similar elements even forms the core of a procedure for product program development, proposed by Blankenburg [5], by analysing similarities in functions and technologies. Reitan proposes [6] a generic procedure based on the product program-related characteristics complexity, variety, commonality and architecture, as introduced by Andreasen [7]. Existing methods from product family design and product design are recommended for the steps of this generic procedure. How these methods are suited to the extra complexity that a product program focus includes is not discussed. Jensen models [8] the product program using a corporate platform in order to "focus on reuse of assets in a broader sense than traditional product platform development". This corporate platform is described using the elements market, product and manufacturing. The literature described above works with an understanding of commonality [5, 6, 8] and on the basis of platform thinking [6, 8]. To better understand how these terms may serve the Development of Modular Product Programs they are discussed below. The reviewed literature provides useful procedures for systematic variety analysis of a product program [5, 8]. Methods for how to exploit this potential using appropriate design solutions are given for focus on a single component [8] or in a generic way [6]. The engineering design support known from product family design is far more concrete than these; thus tools and procedures from this area that might support the development of product programs are presented below.

Development of product families

There are various approaches to the development of modular product families with different focuses in literature. The integrated PKT-approach [1] described above aims to support engineering designers with:

- Concrete design solutions,
- Combinable method units for adaption to a specific corporate situation,
- Visualisation tools that foster indepth product-related problem understanding and team discussion.

The Architecture of a Product Family (PFA) is modelled by Jiao [9] using the functional, behavioural and structural views of a system. The views are described according to their modularity and commonality. Du [10] proposes a generic product structure modelling variant configuration. These models enable

- separating structural elements in common elements and differentiation enabling elements,
- visualising structural elements and their configuration rules.

The modelling of product architectures is treated by Mortensen in [11] in the context of multi product development. Even though the procedures are based on a product family framework, an expansion to product program focus is reconsidered. The modelling of architectures support additionally to Jiao the possibility of modelling

- variety-inducing market applications,
- the handling of product variety in production and supply chain.

While Mortensen [11] and Jiao [9; 10] support the modelling of a product family and provide an overview of its configuration, Krause [1] focuses on analysing its components to redesign them. By doing this, a separation into common components and differentiating components, as proposed by [11] and [9; 10], becomes possible for many components in the first place. However, to support engineering designers in developing product programs both handling the complexity of the task by modelling as well as enabling component reuse by appropriate component design are needed. As modularity is the basis of all approaches it is defined below.

Modularity

Literature defines modularity and modularly structured products comprehensively and in various ways. Salvador [12] identified five modular attributes: commonality of modules, combinability of modules, function binding, interface standardisation, and loose coupling of components. These attributes can apply to a product in various forms and degrees. Just as these attributes are gradual, modularity is a gradual property of a product as well. Consequently, the aim of modularization is not development of a modular product but realization of a suitable degree of modularity according to a corporate strategy [1].

Platform thinking

The term platform has many definitions in the literature. One well-established understanding builds on the definition by Robertson and Ulrich [13], which describes “a platform as the collection of assets that are shared by a set of products”. These assets can be components, processes, knowledge, people and relationships. The broad range of definitions and understanding of the term product platform was analysed by Kristjannson [14], which lead to a definition of the product platform as “a collection of core assets that are reused to achieve a competitive advantage”. These are summarised in Figure 4 (right). The aim of achieving a competitive advantage is also specified and summarized by Simpson [15] and Halman [16] (Figure 4, left). Müller’s [17] definition is based upon this understanding but emphasises that the platform is a cluster of those common assets. In this way, Schuh understands a platform as enhancement of a modular strategy [18] by clustering the common assets of the product variants. While platforms in the literature might be separated into scalable, modular and general, as summarized by Pirmoradi [19], the definition of modularity presented above does not fit this distinction. Understanding modularity as a gradual product property described by the gradual fulfilment of the five modular characteristics named above, a certain degree of modularity needs to be fulfilled for each of the three platform types. Defining a platform as a collection of assets, the question is then one of how a platform can be described and documented when defining this collection for a specific product family. This question is rarely discussed in literature. Nevertheless, some models describing a platform are presented, for example by Andreasen [7]. Summarizing the platform knowledge presented, a very broad definition of a product platform can be derived. Experience in industry showed that this broad understanding is necessary to grasp the various ways that platform thinking is implemented in companies. The platform definition sheet in Figure 4 shows these broad definitions and facilitates a context-specific specification of the definition.

Platform Definition Sheet

A platform is a valid **model** of a modular product family, **clustering** the essential **common assets that are reused** in all includes variants in order to gain specific **platform advantages**.

Specific platform advantages

- ❒ increased the flexibility and responsiveness of the manufacturing processes
- ❒ reduced development time and system complexity
- ❒ reduced development and production costs
- ❒ improved ability to upgrade products
- ❒ customization by enabling a variety of products to be quickly and easily developed
- ❒ better learning across products
- ❒ reduced testing and certification of complex products
- ❒ increased the speed of a new product launch

Data used for modelling the product platform

- ❒ guidelines and design rules
- ❒ chart of reuse and differentiation
- ☐ …

Common assets clustered and reused

- ☐ knowledge
- ☐ functionality
- ☐ design variables
- ❒ architectural rules
- ☐ people and relationships
- ☐ processes
- ☐ product basis
- ☐ technology
- ❒ interfaces
- ❒ modules
- ❒ components

Figure 4 Platform definition sheet derived from literature review on the example of the product platform understanding of institute PKT (☑)

Commonality

The term commonality is used to describe the reuse of components by Robertson, Thonemann and Fellini [13; 20; 21]. Jiao classifies commonality in functional, technical and physical commonality and extends this understanding from commonality of physical components to commonality of customer requirements and technical parameters [9]. Even Dellanoi extends the understanding of commonality and classifies component commonality, solution commonality, structural commonality and process commonality [22]. Andreasen [7] turns a possible classification of commonality into a generic definition. Modules can show variety and commonality at the same time. Being identical to a specific system (e.g. purchase or production), they can show commonality even when they are physically non-identical. As this understanding of commonality may be very useful in cases where standardisation (component commonality) cannot be achieved due to high claimed external variety or technical constraints, the definition shown in Figure 5 is used in the development of product programs.

Definition Product Commonality

Product commonality is the relative property of being designed in a way that the variety of product variants to each other leads to possibly low complexity in a specific company. This may be achieved by the reuse of components, solutions, product structures or interfaces. Common interfaces to the process systems enable process commonality.

Figure 5 Definition of product commonality used for the development of product programs

Implications for supporting designers in the Development of Modular Product Programs

To develop a methodical approach that supports the Development of Modular Product Programs, the implications of the literature study described above are allocated to the refined research task derived from industrial case studies.

Defining a corporate product structure strategy

Initially, activities can be subdivided into activities within and across product families. This helps to allocate and name different activities. These activities mean product design activities that raise product commonality. A corporate product structure strategy needs to be defined to set a framework for the systematic analysis and reduction of variety. Depending on the product program, there might be lots of potential for product family internal commonality. In this case, it is recommended that a classical product family oriented platform strategy is followed (Figure 6, left). Other product programs might have good potential for carry-over of parts, components and modules across product families. They should be designed as a configurable modular system of smaller modules with a strong focus on carry-over across product families (Figure 6, right). A lot of product programs might show potential for both directions of commonality – within and across product families (Figure 6, middle).

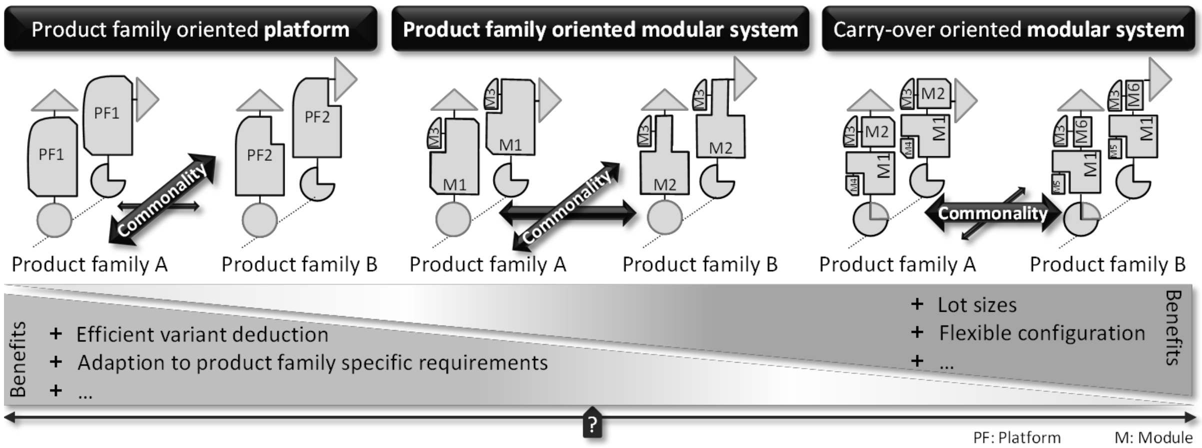


Figure 6 Product structure strategies and their focus on commonality within and across product families [23]

The corporate product structure strategy should be derived from carry-over potential. This can be done by performing Product Program Planning [4], evaluating the number of carry-over candidates within and across product families and choosing the strategy accordingly. Having defined the corporate product structure, the potential for commonality, as analysed by Product Program Planning, needs to be investigated and designs tasks need to be derived. Product platforms can support the implementation of a product structure strategy as a tool for achieving structural commonality, which fosters common components and configurability of carry-over components across the product program. Modelling the whole product program using product platforms, this model becomes a tool for aligning and managing the design tasks within and across product families and can even be used for carry-over oriented strategies. These design tasks can be performed as projects supported by Steps 1-7 of Design for Variety and Life Phase Modularization, as described above. They can be distinguished into tasks within product families, which follows the common procedures for product family design, and into design tasks across product families, i.e. development of component families, which is especially challenged by the broad range of external variety and technical constraints, as the components need to be designed for carry-over across several product families. How this can be supported in addition to the steps and tools of Design for Variety and Life Phase Modularization is described below.

Tailoring technical solutions to the specific corporate needs

The design task of developing component families is restricted by market-driven constraints and technical constraints caused by conflicting needs. The VAM shown in Figure 2 is a suitable tool for analysis of the technical constraints. It demonstrates how the customer-required variant properties are connected to functions, working principles and components. The more variant properties influence a component, the more technical constraints lead to requiring a broad variety of these components. This can be reduced by appropriate Design for Variety. However, total decoupling is, in many cases, not achievable when working with the variant range of a product program. To reduce variety in the given constraints, commonality, as defined above, is an appropriate solution. Figure 7 shows that many stakeholders want to influence the variety of a component. They represent a product's requirements during its life phases e.g. procurement, assembly or sales. The idea of live phase commonality means interviewing each stakeholder about the need for differentiation or standardisation, and to find design solutions to make the required variety of a component common to the system that requires standardisation. This step can be understood as an enhancement of the Life Phases Modularization by first tailoring the commonality of components to each life phase and then merging them to modules according to the needs of each life phase.

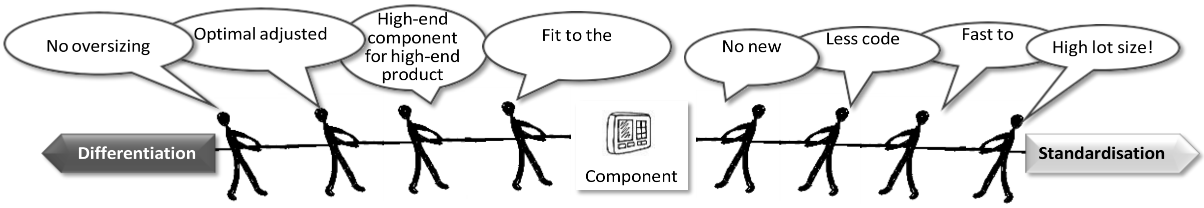


Figure 7 Conflicting needs for differentiation and standardisation [23]

Summary and future prospects

The Development of Modular Product Programs has potential to reduce variety that exceeds the potential of product family design as analysed in industrial case studies. Systematic approaches for supporting the engineers in this task are only roughly described in the literature. This contribution proposes to derive a product structure strategy from Product Program Planning, and its implementation based on product platforms. They serve as a tool for aligning the use of variant and common components within a product family and of carry- over components across families. The development of carry-over components is challenging because of the broad range of external variety and technical constraints. Life phases commonality means finding solutions appropriate to the need of each life phase according to these constraints. It supplements the toolkit of the integrated PKT-approach. The ideas for tools and steps of a methodical unit for the Development of Modular Product Programs derived from industrial case studies and presented in this paper will be refined and merged into an appropriate procedure in case studies on industrial trucks and safety equipment.

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