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# A METHODICAL APPROACH FOR DEVELOPING MODULAR PRODUCT FAMILIES

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**ABSTRACT**
To offer individualised products at globally marketable prices, Institute PKT's integrated approach for developing modular product families aims to generate maximum external product variety using the lowest possible internal process and component variety. Methodical units of design for variety and life phases modularization support the creation of modular product structures on the level of conceptual design. During embodiment design modular attributes are enhanced through module and interface design according to corporate needs integrating further requirements on product properties. The methodical approach is explained in example of a product family of herbicide spraying systems

*Keywords: Design for Variety, Modularization, Methodical Product Development, Product Family, Product Architecture*

## 1 INTRODUCTION

For new products, the extent to which a product meets the challenges of modern market situations is determined during product development. It is important to address contradictory and competing factors and developments. Globally intense pricing competition as well as the megatrend of individualisation is reflected in the conflicting customer requirements of low prices and personalised products. These two scenarios result in two product development strategies. The aim is to develop standard mass-market products to offer competitive prices - the focus being on the advantage of large quantities of the same products. On the other hand, to be able to make a profit, a high number of individualised products can be a successful way to meet individual customer requirements. Both strategies involve chance and risk. In product development, the strategy for developing modular product families is ideal for combining the advantages, such as individual customer demands, with low costs to be well prepared in the future.

The aim of developing a modular product structure for a product family is to maintain the external variety required by the market and reduce internal variety within the company to handle, reduce or avoid the associated complexity of corporate processes in product development. A major advantage of this strategy is the larger quantity of standard modules derived that contribute to cost reduction, for example, with better utilisation of economies of scale and learning curve results, especially in procurement, production and assembly. Modular structures provide the opportunity to parallelise any processes, e.g. to develop different modules in parallel or to test or produce them separately.

This paper presents an overview of the integrated approach for developing modular product families developed during several research projects at the Institute PKT, starting with an introduction of the basics of modular products and strategies for controlling external variety before describing the approach itself using a case study on herbicide spraying systems. Continuing and future research projects within the development of modular product families are then presented, motivated and integrated.

## 2 THE FIVE ATTRIBUTES OF MODULAR PRODUCTS AND THEIR EFFECTS

The literature defines modularity and modularly structured products in various ways. A comprehensive definition permits the description of common attributes of modular products [1]:

- *Commonality of modules*: Components or modules are used at various positions within a product family.
- *Combinability of modules*: Products can be configured by combining components or modules.
- *Function binding*: There is a fixed allocation between functions and modules.
- *Interface standardisation*: The interfaces between the modules are standardised.

- *Loose coupling of components*: The interactions between the components within a module are significantly higher than the interactions between components of various modules.

Figure 1 is a summary of the five attributes of modular product structures. These attributes of the modularity are characteristics of a product in various forms and degrees. Just as these attributes are gradual, modularity is a gradual characteristic of a product as well. Consequently, the aim of modularization is not the development of a modular product but the realisation of a suitable degree of modularity adapted to the corporate strategy.

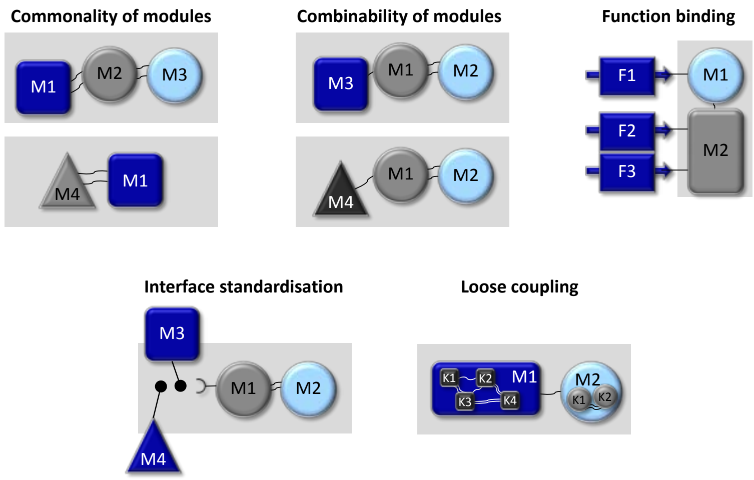


*Figure 1. Attributes of modular products (F: Function, C: Component, M: Module) cf. [1]*

The modular structure of products and product families can have advantages in every life phase of a product (Figure 2). Yet the potential and limitations of modular product structures have to be considered. The modular structure of a product may inhibit the optimisation of the overall function of each individual product variant. This results in risks in the modularization, such as over-dimensioning, additional interfaces and a lack of product differentiation for the customer.

Analysing the potential and limitations of modular product structures shows that during development of modular products the degree of modularity chosen has to take full advantage of the potential of modular product structures while fulfilling company-specific goals and avoiding negative effects.

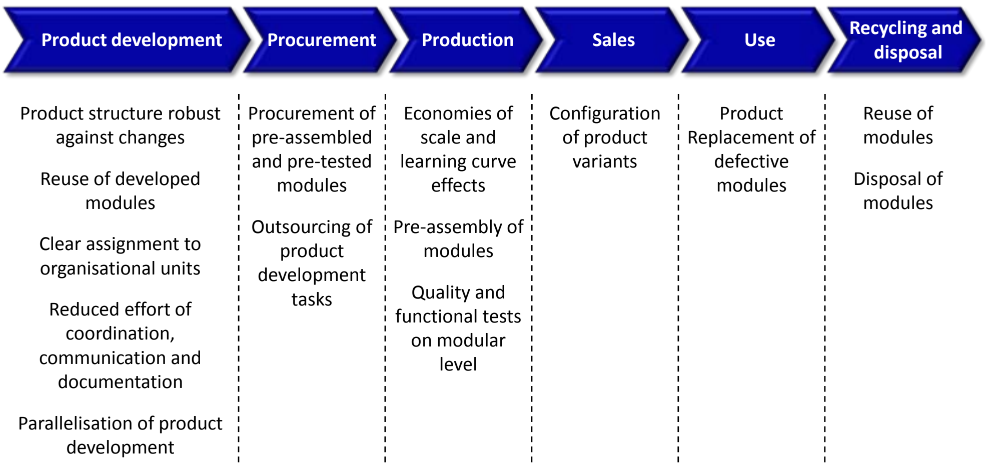


*Figure 2. Advantages of modular structures for the product life phases cf. [2]*

## 3 STRATEGIES FOR CONTROLLING EXTERNAL VARIETY

To control the variety demanded by a broad spectrum of customers, companies can follow product-based and process-based strategies, or combinations thereof. As well as the strategy of providing a modular product family, product-oriented strategies also include the *platform strategy*, which is an expansion where a platform, as a basic module applied to a product family, is defined as standard.

A modular product structure adapted to corporate goals allows orientation towards complexity-reducing process strategies, as they are closely related to the product structure. *Process commonality* describes the strategy of using the same processes for different products to counteract the variance of a product family by unifying the processes. A *postponement* strategy enables the greatest possible part of the production process to be independent of variants. Postponement is the delay of processes that are variant. This means that the variant-specific process steps are at the end of the process, if possible.

## 4 EXISTING APPROACHES IN THE DEVELOPMENT OF MODULAR PRODUCT FAMILIES

To reduce internal variety of product families, approaches in design for variety provide the possibility to develop a product structure that is optimized for effective variant derivation through communality. This results in component designs and product structures that reduce internal variety but do not meet the requirements of other stages within the product life phases (such as sourcing or manufacturing) [3].

Modular product structures can on one hand enhance combinability and on the other hand reduce the negative impacts of internal variety on a company by exploiting the benefits of modular product structures over all phases within the product life (Figure 2). There are three main steps in existing modularization methods [4]:

1. Decomposition of the product up to the level of the components.
2. Analysis and documentation of the components and their couplings.
3. Analysis of the possibility of reintegrating the components.

These existing, often highly matrix-oriented, approaches, such as the Modular Function Deployment [5] and the Design Structure Matrix [6], were developed and will be further developed at a number of institutes, for example, Structural Complexity Management [7]. An approach based on a product’s function structure is presented in [8]. These appraoches mostly led to a regrouping of components.

In [3], existing methods in design for variety as well as in modularization are outlined to find an integrated approach that reduces variety in modular product families comprehensively, taking effective variant derivation as well into account as reducing the negative impacts of internal variety across all product life phases.

A broad literature review of product family design is given in [9], including configurational product family design as well as production and supply chain issues. The need to align appropriate variety with reduced complexity over the product life phases and appropriate commonality is explored in [10], which provides basic definitions and relationships.

## 5 PKT’S INTEGRATED APPROACH FOR DEVELOPING MODULAR PRODUCT FAMILIES

PKT’s integrated approach extends the idea of designing for variety while meeting requirements from other life phases. All life phases need to be considered to exploit the advantages of modular product structures over the whole product life. The benefits of modular product families can be enhanced by including new technical solutions instead of just regrouping existing components.

The aim of the approach is to reduce internal variety, integrating these comprehensive aspects without cutting the customer-required external variety through different methodical units (Figure 3). It includes the unit of design for variety, which means the redesign of components in terms of variance reduction, and allows the integration of new requirements or functions. This step is followed by the actual modularization, which considers all specific requirements defined by the relevant product life phases and is therefore called life phases modularization. During embodiment design, the modular attributes are enhanced. These units are described in detail in the following sections. Ongoing research is done on a more strategically focussed unit, product program planning, to find ways to reduce internal variety at an earlier level within the redesign/design of a product family.

To carry out a process-based evaluation of alternatives for modular product structures for a product family, a further important methodical unit is the integration and coordination between the product development processes for commonality, the postponement strategy and the product architecture.

The methodical units build PKT’s integrated approach for developing modular product families, integrating comprehensive ways of reducing internal variety in one framework of matched tools and methods.

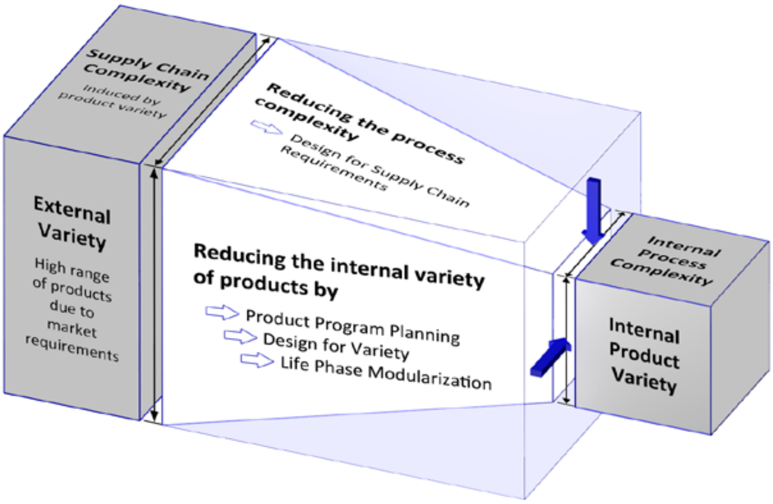


*Figure 3. PKT's integrated approach for developing modular product families*

## 6 CASE STUDY OF A MODULAR PRODUCT FAMILIY

A detailed case study using PKT's integrated approach for developing modular product families was conducted on a family of spraying systems for herbicides that were the subject of the AIF-founded research project AUXESIA. The MANKAR-Roll family by Mantis ULV consists of Ultra Low Volume (ULV) Spraying Systems for herbicides. The existing product families consist of 12 actively advertised variants as well as 24 additional variants provided on special customer request (Figure 4). These variants adjust the spraying systems to the individual application conditions of the customers working within professional in-row cultivations or public places via different spray widths or sizes of wheels, for example.

*Figure 4. Product variants of the product family of herbicide spraying system MANKAR-Roll*

## 7 DESIGN FOR VARIETY

Design for variety is a methodical unit developed within a research project at PKT [3]. It brings the product families closer to an ideal, allowing a description to be made. This ideal is defined by four characteristics:

1. Differentiation between standard and variant components.
2. Reduction of the variant components to the carrier of a differentiating attribute.
3. One-to-one mapping between differentiating attributes and variant components.
4. Complete decoupling of variant components.

In the first step of the method, the external, market-based and the internal company variety of the product family are analysed. A tree for differentiating attributes aids analysis of the external variety (Figure 5). This tree visualizes the selection process of the customer. Internal variety is analysed at the levels of functions, working principles and components. The variety of functions is shown in an enhanced function structure that makes representation of variant and optional functions possible. The variety of working principles is determined from sketches, where the necessary variance of the functional elements is marked in colour. The specially developed Module Interface Graph (MIG©) is used to analyse the variety of components [2]. The MIG provides a schematic representation of the rough shape and arrangement of the components and their variance, as well as the structural connections and the power, material and information flows. This enables their inclusion when defining modules and reducing variant components.

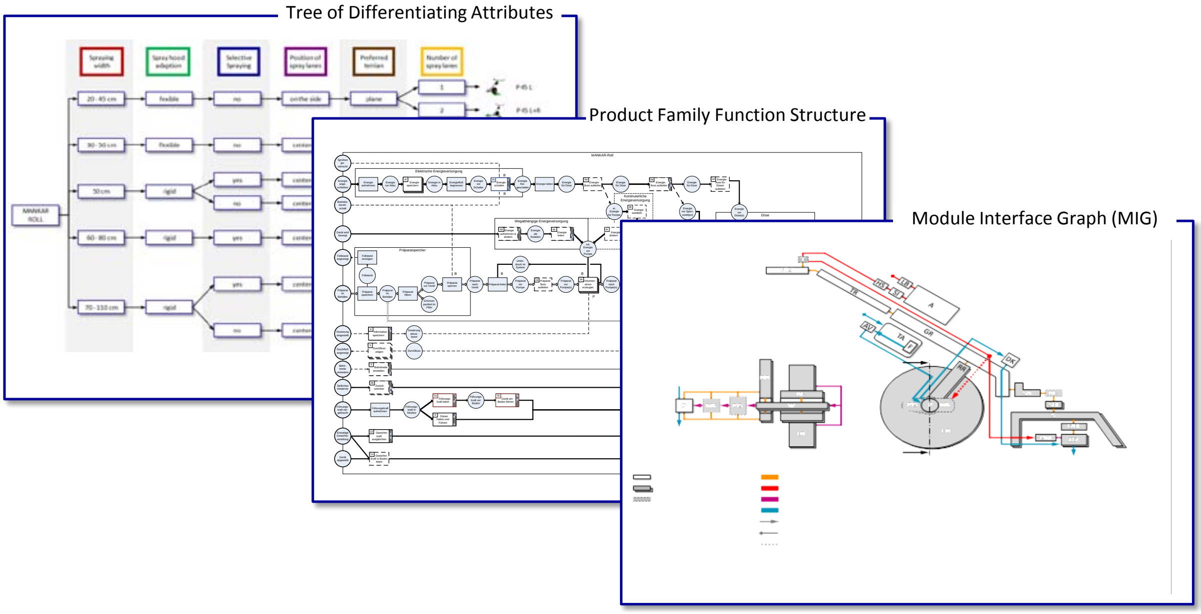


*Figure 5: Tools for the analysis of product variety [3]*

All relevant information required to carry out design for variety when preparing constructive proposals is visualised in the Variety Allocation Model (VAM©) [3]. The connections between the levels demonstrate the allocations between differentiating attributes, functions, working principles and components (Figure 6). In this way, VAM allows analysis of the degree of fulfilment of the four ideal characteristics. For variant conformity, any weak points in the design can be identified at all levels of abstraction. Thus, VAM is the basis for solution finding and selection of solutions in the methodical unit of design for variety.

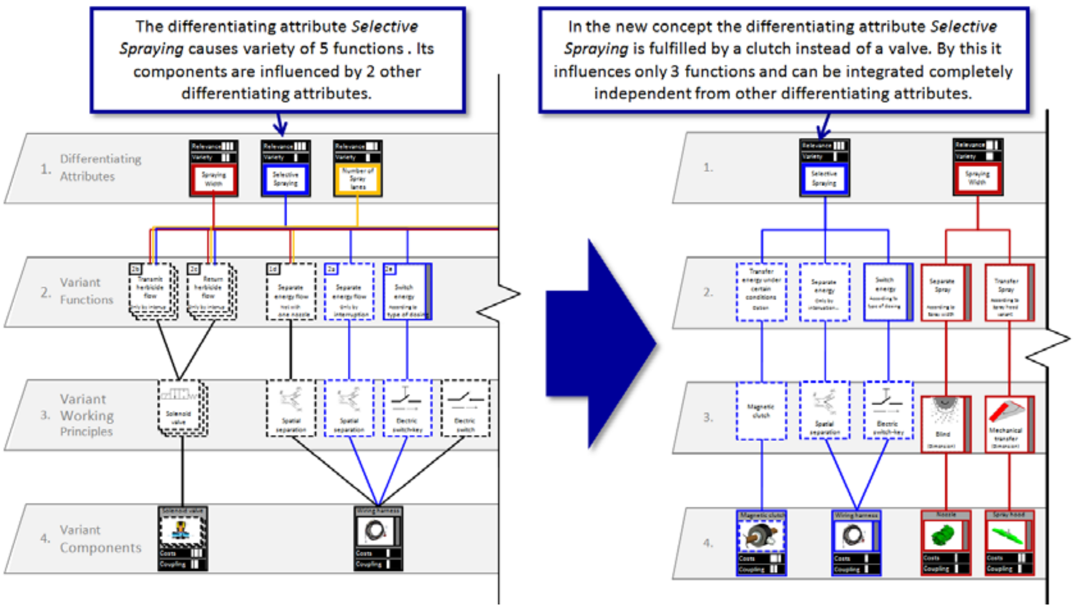


*Figure 6. Applying the Variety Allocation Model (VAM) cf. [3], [11] as a tool to optimize the product family of herbicide spraying systems*

The result of this methodical unit is a newly designed set of components with an increased number of standard parts. Multiplication effects of the variance are avoided, with the result that each component is required in a small number of variants. The simplified allocation structure between components and differentiating attributes simplifies the variant configuration. These benefits were achieved by using the VAM as a tool to optimize product structure following a product's differentiating attributes, functions and working principles. By considering differentiating attributes as well as functions and working principles, the methodical unit enriches the field of existing approaches with a method that aligns a market-oriented view with a function-oriented one.

## 8 LIFE PHASES MODULARIZATION

Life phases modularization is a second methodical unit in the development of modular product families developed within a dissertation at PKT [2] in order to use the results of the product design for variety for each individual relevant product life phase, as well as to check their consistency and adjustment to a continual module structure. Product structure requirements can be better met by considering different product structures for individual phases. The procedure is divided into the following steps:

1. Development of a technical-functional modularization as the modularization of product development life phase
2. Development of modularizations for all relevant other product life phases
3. Combination of modularizations
4. Derivation of the modular product structure

The starting point is the technical-functional modularization of the product development phase. Modules are provided that are largely decoupled to reduce the complexity of the development task and allow parallel development of modules. Technical functional approaches, as for example described by Stone [8], can be applied at this step. The development of modularization perspectives of all relevant product life phases is made by module drivers associated with individual life phases. For instance, the production phase is mapped by the module driver 'Separate Testing' (Figure 7).

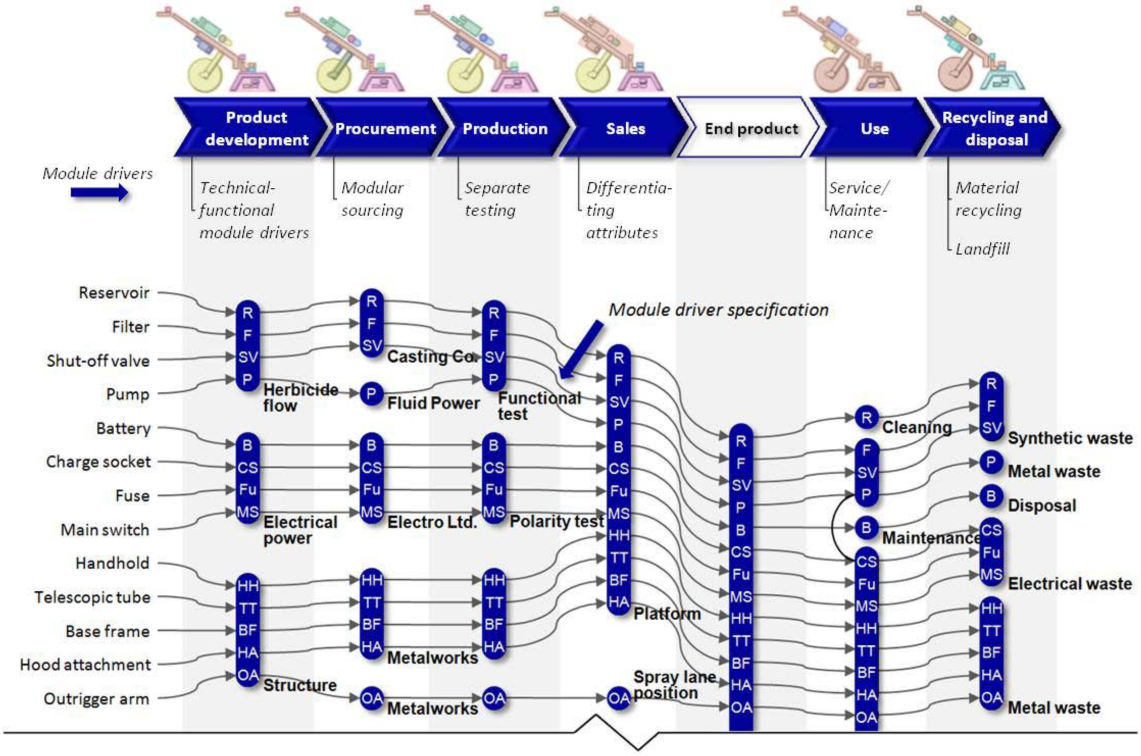


*Figure 7. The Module Process Chart (MPC) as a tool to allocate module drivers and module driver specifications to modules cf. [2]*

The module drivers are a known concept from [5] but have been supplemented with concrete specifications for the development of modules. In the module driver 'Separate Testing', the tests to be carried out demonstrate the product-specific specifications. In network diagrams, these specifications are linked to the components of the product. The preparation of modules is made by grouping the components that relate to a common module driver specification into one module. Subsequent to the development of modular product structures for the individual life phases, the modularizations are visualised in a MIG to allow consistency checks between the different life phases and demonstrate any conflicts. It was found that it is not sufficient to develop the same module structure for all life phases that cannot be realised because of the different and contradictory criterions. Rather, it is important that the module structures of the individual phases are adapted and continuous but not 100 percent congruent. For assembly, it may be advantageous to install a module that is as large as possible. For purchase, it may be necessary to buy this module in the form of smaller modules from different suppliers which, in case of a well-adapted structure, must not be contradictory. The *Module Process Chart (MPC)* transparently combines the various perspectives of different life phases and makes the coordination process more clear (Figure 7). Finally, the product structure can be derived.

## 9 MODULARITY IN EMBODIMENT DESIGN

After the modular structure of the product family is defined during conceptual design, the modules and their interfaces are further specified through embodiment design. Figure 8 shows how the steps of PKT's integrated approach for developing modular product families are related to the product design process for single products, following VDI Guideline 2221. In PKT's integrated approach, conceptual design concludes with the definition of a modular product structure. Other approaches place modularization within embodiment design [12] as they do not include redesign in aspects of variety in conceptual design.

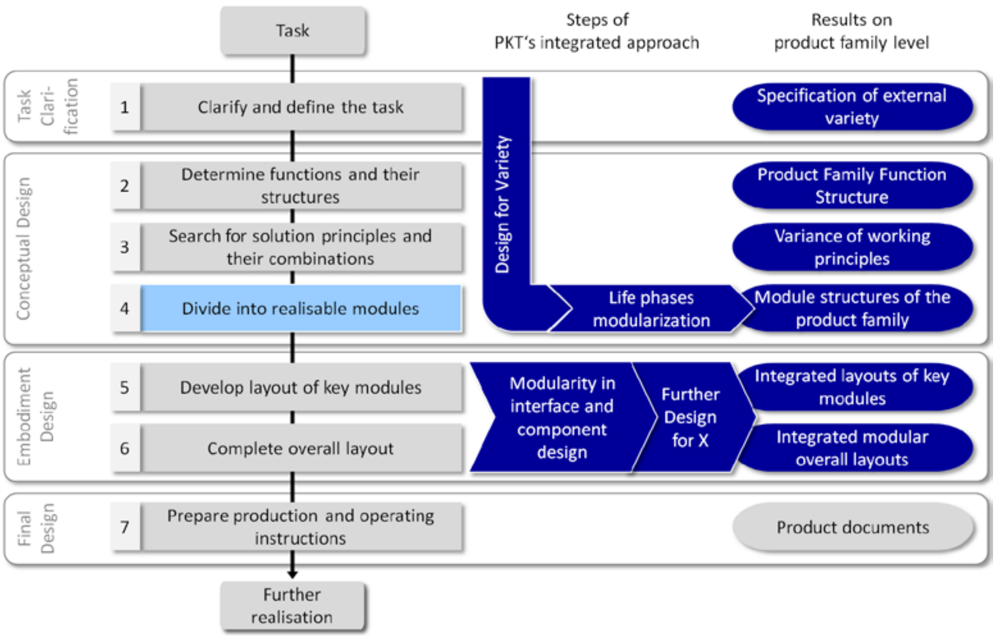


*Figure 8. PKT's integrated approach related to product design after VDI Guideline 2221*

At the beginning of the embodiment design phase, the level of operation is within modules and on interfaces between modules. This change of level enables clear allocation of the design phases. Yet the development of product families is an iterative process.

Regarding the attributes of modular products we see that even the design of single modules and interfaces affects attributes such as loose coupling or interface standardisation (Figure 1). During embodiment design, these attributes can be given to the product family and so influence how the modularity of the product family meets corporate needs. The challenge during embodiment design is thus to realize all the benefits of the modular product structure defined during conceptual design and to further enhance the modularity and its corporate benefits with the design of single modules and interfaces.

Further requirements of the product family that are not directly related to variety and modularity need to be considered during embodiment design as well. Examples of these requirements are ergonomics and aesthetics, and others commonly summarised under the term Design for X [13], or lightweight design or eco design. Addressing these requirements often influences or is influenced by the modular product structure. Thus, a second challenge within embodiment design of modular product families is meeting different product requirements, e.g. fulfilling specific Design for X guidelines while realizing optimal modularity.

Initial studies of how to meet these challenges during embodiment design of modular product structures were carried out on herbicide spraying systems. Industrial design was one of the requirements addressed after defining the modular product structure. Industrial design concerns the product family in particular regarding the corporate styling over the whole product program and ergonomic design. Applying the attribute of modular products 'loose coupling' components of the product platform are integrated in one body housing. The body housing itself can now integrate aspects of corporate styling and ergonomics without compromising the benefits of modular product structure. For instance, the generic product module is centred close to the wheel to optimize the product's balance point and, by this, its ergonomics. Lines, colours and shapes of the product platform can be freely designed according to corporate design without being influenced by variant components. The resulting concept is shown in Figure 9.

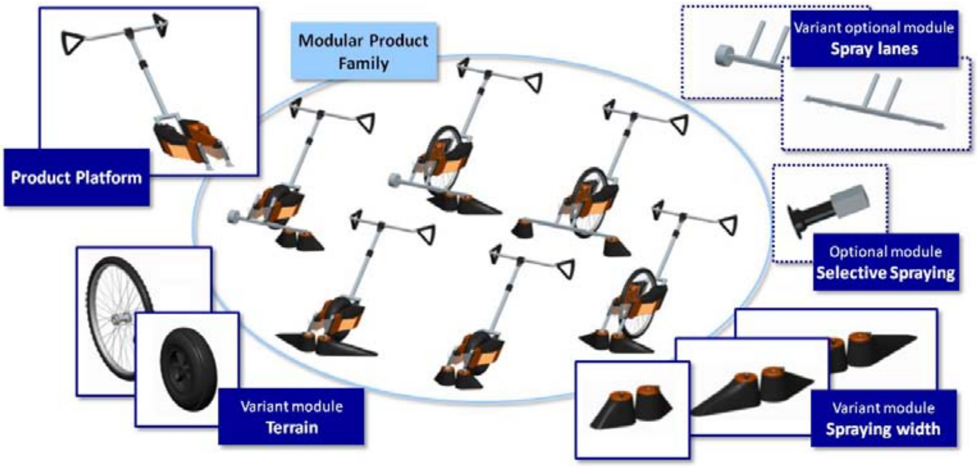


*Figure 9. Modular sales concept of the MANKAR-Roll family with integrated aspect of ergonomics and corporate styling*

## 10 RESULTS OF THE CASE STUDY

During the case study described above, a product concept for a modular product family of spraying systems was developed and detailed through embodiment design. The new product family enables the configuration of 64 product variants, including the required existing variants, where 32 are supposed to be actively advertised while 32 are more seldom needed on customer request. Through design for variety, internal variety was reduced from 46 components to 32 components (Figure 10). Through life phases modularization, the product structure was additionally adapted to the specific needs of product life.

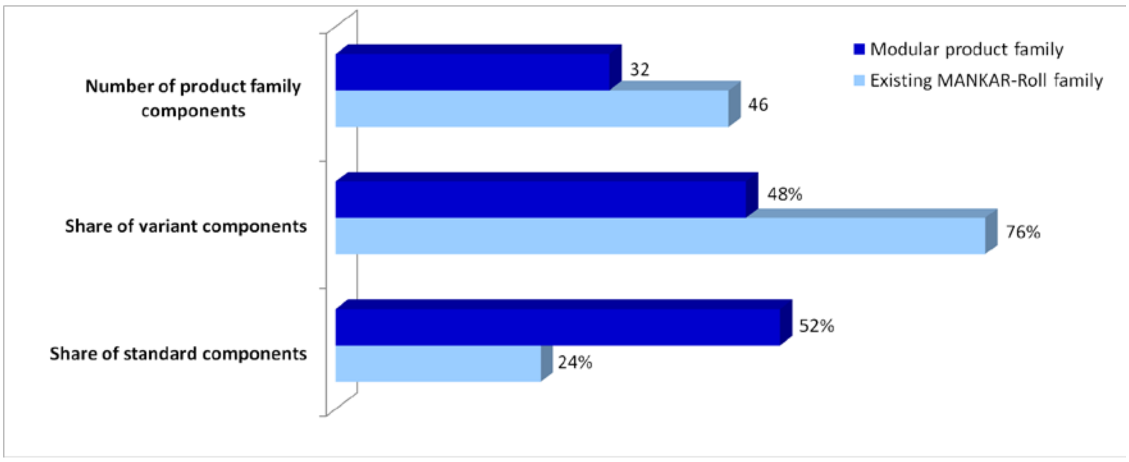


*Figure 10. Results of the case study on spraying systems, derived by applying VAM*

The new modular product structure enables a postponement strategy, which allows distribution partners to purchase a low number of product platforms and variant modules while offering a high number of variants. This new flexibility enables effective pre-assembly before order inflow and reduces capital and material commitment through stock [14] as every ordered variant can be derived from the same platform and specific variant and optional modules. A high share of standard components (52%) within the product platform, includes the higher part of total component costs (Figure 10).

## 11 CONCLUSION AND PERSPECTIVES

PKT's integrated approach for developing modular product families enables the reduction of internal variety while maintaining external customer variety. This was verified by the case study as well as in further industrial case studies carried out in the last two years. The approach contains the methodical unit of design for variety. This unit includes steps within conceptual design to optimise the structure of a product family at the levels of functions, working principles and components by partial redesign. The conceptual design ends with the modularization of this redesigned product structure considering specific module drivers of generic product life phases to adapt the optimised product family structure to the needs of the whole product life. By this, the integrated approach aims to optimize the product family structure through conceptual design while other approaches allocate modularization within embodiment design as it is classically seen as a grouping of technical solutions without adapting the solutions themselves to the needs of a variant modular product family.

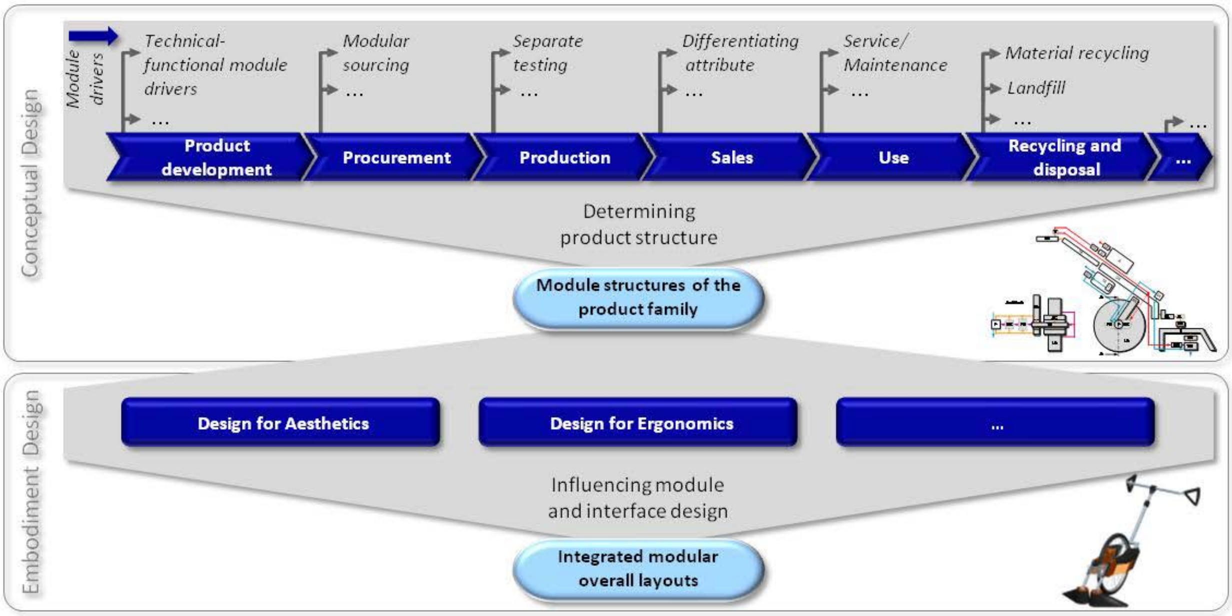


*Figure 11. Influence of requirements on product life and product characteristics in conceptual and embodiment design of modular product families*

Within embodiment design, the product structure itself is set. The design of interfaces and modules is still to be accomplished with the aim of realising the modular attributes of interface standardisation and loose coupling according to corporate needs. This has to go along with embodiment design according to specific Design for X guidelines. Figure 11 shows how requirements of generic product life phases and product properties are integrated into the development of modular product families. Within the case study, requirements of generic life phases are defined as module drivers to determine the modular product structure. Requirements of specific product properties influence the embodiment design of interfaces and modules, for example, through Design for X guidelines. In Figure 11, the set of requirements and their influence on the case study are shown. The next step for research is using the generic life phases as a basis for defining module drivers that need to be individualised to specific corporate priorities. The requirements that have priority in determining modular product structure as a module driver can then be chosen. Requirements that are subordinate to those considered as module drivers or that can be met within separate modules are considered during embodiment design.

How the specific requirements of lightweight design and design for assembly can be integrated along the process of developing a modular product family is considered in the current research projects of Module Lightweight Design and Modularization for Assembly.
A further field of research is to extend PKT's integrated approach to the redesign of product programs to enhance the share of carry-over parts through modular product structures within the product program.

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