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METHODOLOGY FOR PRODUCT STRUCTURING IN THE EARLY STAGES OF THE DESIGN PROCESS

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Abstract

A common concept to increase product variety with low process costs is the design of modular product families. The following contribution describes an approach to a methodology supporting the early stages of design process of modular product families. In a first step of this methodology a customer/market view of the product family is described. Additionally, a business process view is also defined. Both views are described by properties with characteristics and parameter values. The next step consists of the determination of a first module structure from a functional decomposition of the product family. This module structure is one part of the technical view of the product family. In a further step the variety of each module is described with properties. Based on the defined views, a first product structuring is performed from an aspect of order. This structuring is supported by a matrix system in order to achieve a wide external variety with a limited internal variety. Thereafter structuring from an aspect of product structure is accomplished. At this point decisions concerning standardisation and re-use of components take place.

Keywords: product structuring, product family, variety, modularisation, standardisation

1. Introduction

Increasing individualisation of markets, globalisation of company structures as well as accretive dynamics of technological progress and shorter cycles of innovation are current tendencies of the industrial environment. Due to this, most companies are reacting with optimisation of existing products, improvement of production processes and enhancement of attractiveness on the market. Indeed, success of such measures is very short termed. Beneath of the described so-called cost-management issues, companies have to be responsive to individual customer requirements by offering individual variants of the product. This leads to the difficult task of reducing business process costs of such customised products.

Due to the fact that 70% of the product costs are determined in early stages of the engineering design process [1], an optimisation should take place in an early process step of product design. A methodology is required, in order to support the conceptual design process of modular product families considering product life-cycle aspects.

The objective of this contribution is to present a methodology to support development of modular product families. Besides the customer requirements this mryhodology should cover the requirements of the different business processes such as:

- engineering,
- manufacturing,
- assembly,
- sales,
- and maintenance

in an appropriate way.

Different existing definitions of the term product family may lead to confusion. To avoid this, the definition used in this contribution is given as follows: a product family consists of several product variants with identical internal interfaces (technological, functional, physical) [2]. In the context of this paper the term product family is also used as a synonym for variant products.

In the following chapter a brief overview about existing methodologies in the area of modular product family design is given. The need of an approach as proposed in this work will be explained. Then the methodology for product structuring in the early stages of the design process will be introduced and illustrated with an example.

2. Existing methodologies

The design of modular product families is a common concept to increase variety with low process costs. To support this design, many approaches have been presented in literature over the last years. Modular Function Deployment (MFD) [3], Design for Variety (DfV) [4] as well as Modular Product Architecture (MPA) [5] are just a few examples. All of them have one thing in common: they focus on specific aspects in the process of modular product family design [6]. MFD is an approach which aims to achieve a modularisation by rating the sub-functions of the future product family in respect of so-called module drivers. In a further step the interfaces between the evaluated modules are considered and optimised. The main goal of DfV is to develop a decoupled architecture that requires less design effort for follow-on products. This takes place by assessment of indices which describe either external drivers on the product structure or correlations between components. The approach of MPA suggests a decomposition of the individual products of the product family in individual function structures as proposed in [7]. Based on this defined function structures, an overall function structure for the whole product family is assembled. Starting from this structure modules can be identified by a set of heuristics [8]. Results are listed in a so-called Modularity Matrix and common as well as unique modules of the product family can be defined.

Although the methodologies described above are very powerful, this contribution describes another approach. The aim is to consider different aspects of modular product family design like definition of modules, external and internal variety, standardisation as well as re-use of components and product life-cycle aspects. The reported methodology builds a framework with the ability to integrate other existing methodologies as well.

3. Methodology

The overall approach to the methodology for product structuring is shown in Figure 1.

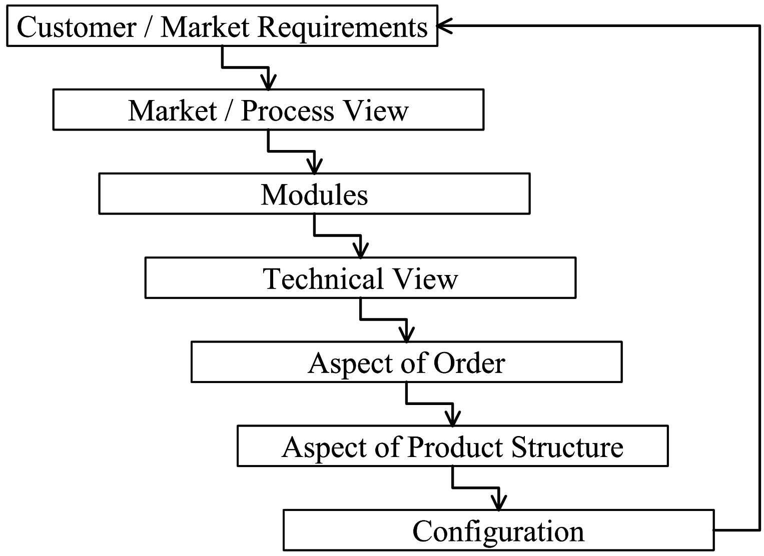

Figure 1. Overall procedure of product structuring.

The initial point for product structuring in the early stages of the modular product family design is the evaluation of *customer requirements*. Herewith the product family can be clearly described and positioned in the market. Starting with these requirements the *customer/market view* of the product family is described in order to characterise the product variants by properties. Moreover the product family is also described by business process-relevant properties. Thereby a property is a combination of a characteristic and a parameter value (Figure 2) according to [9].

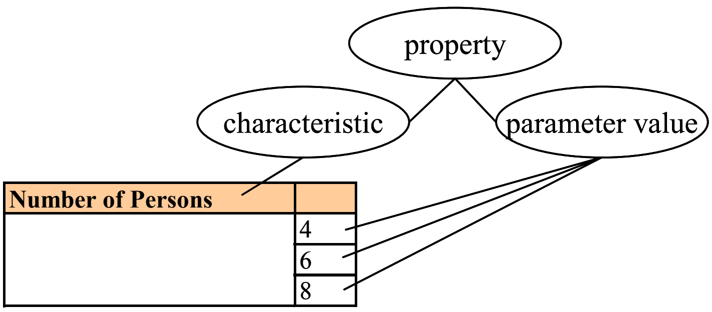

Figure 2. Description by property.

Further, a first module structure has to be defined. The basis for this module structure is a functional consideration and a decomposition of the product family. This way the *modules* can be defined as functional units (Figure 3). At the same time, other criteria have to be considered like: company-external factors (e.g. customer demands, regulations, laws) as well as company-internal factors (e.g. future developments, production and assembly requirements). The definition of the module structure can be supported by widespread methods such as Modular Function Deployment (MFD) [3], Modular Product Architecture (MPA) [5] or by functional models as described in [8].

The module structure is one part of the *technical view*, which represents the product family from the point of view of the technical departments. The essential element of the technical view is the specification and refinement of the module structure defined above.
In the early stages of the product design, this module specification is done by properties (Figure 3). Thereby the main focus is on the description of the variety of each module, in order to implicitly specify all possible variants of a module.

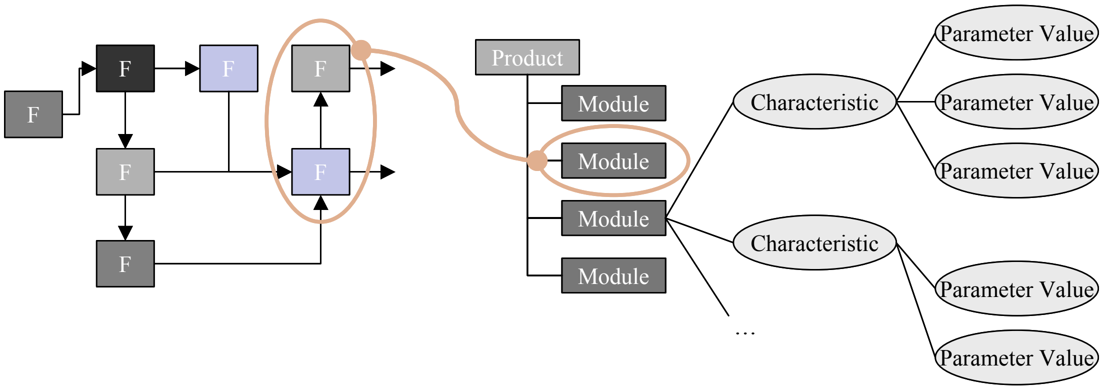

Figure 3. Description of technical view.

Based on the defined market and technical view, design teams can structure the product family from the *aspect of order*. The main instrument of the order aspect consists of a matrix-based product modelling method as described in [10]. It consists of two types of matrices representing inter-domain relations (different element types in rows and columns / relations between elements of the different type in the cells) and intra-domain relations (same element types in rows and columns / relations between elements of the same type in the cells). These two types of matrices are combined to a matrix system (Figure 4) similar to the K & V–Matrix method [11], [12] as follows:

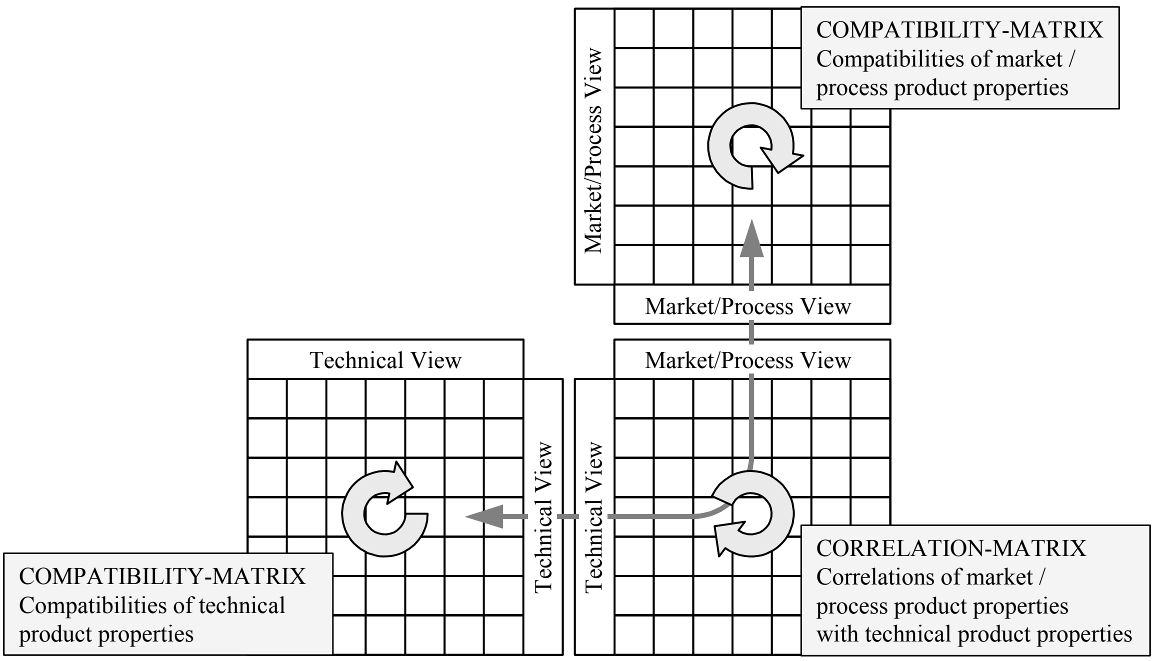

Figure 4. Matrix system.

The correlation matrix (Figure 4, right), represents the impact of customer relevant requirements as well as business process relevant requirements to the technical view of the product family. It shows the direct cause of variety in a module (originated by customer or (technical) process demands) and acts as a control mechanism to define a reasonable variety in the modules.
A second matrix defines the compatibilities between individual properties of the market/process view (Figure 4, right). Therefore it represents possible combinations of customer demands offered in the market. This matrix gives an impression of the product family variety, as it is represented to the customer (external variety) [13].
A third matrix defines the compatibilities between individual properties of the technical view (Figure 4, left). Therefore it represents possible combinations of technical properties that may be engineered and realised. This matrix gives an impression of the product family variety, as it is generated in the company (internal variety) [13] and points out the product family complexity to be managed in business processes.

By coupling the three matrices with each other (Figure 4), it is possible on the one hand to analyse changes in the technical view (properties or compatibilities) and its effects to the market/process view (properties or compatibilities) and vice versa. On the other hand it supports design teams analysing the influence of the customer demands on the modules. Thereby possible discussions are the following examples:

- Which market properties may be deleted and what are the consequences for the customer variety as well as the technical view (variety of modules)?
- Which module properties may be deleted and what are the consequences for the technical variety as well as the customer variety?
- What is the influence of technical compatibilities (and thus the module variants) to customer variety and vice versa?

The compatibility matrices can be used to analyse the ratio of internal and external variety. The aim is to structure the product family in order to enable a wide external variety with a minimised number of module variants.

The next step in the structuring process consists of evaluating the product structure considering standardisation and re-use of components across the product family. The purpose of this *product structure aspect* is to concentrate the variety on specific modules by shifting effects of variety-drivers e.g. customer demands. Each module has to be detailed in terms of an order-neutral product structure and has to be optimised according to reasons related to the external and internal variety as well as the assembly process. The objective is a strict partitioning of variable (customer specific) and standardised (customer neutral) modules.

To complete the product structuring, the last step consists of the specification of further *configuration knowledge*, in order to make this structuring available for the configuration process.

4. Example

In this chapter, an example of an elevator product family is presented. Thereby, the main focus is set on the described aspect of order.

In a first step customer/market view is defined on the basis of customer requirements. This view is described by properties. Further a first module structure is defined based on the

functional decomposition of the product family. The variety of each module is described by properties.
Based on the defined market and technical view, the correlation-matrix is described. Figure 5 shows a fraction of this matrix. The correlations between the different views indicate the direct cause of variety in the modules. For example the module "power unit" is correlated with the characteristics "number of floors", "motions per hour" and "number of persons".

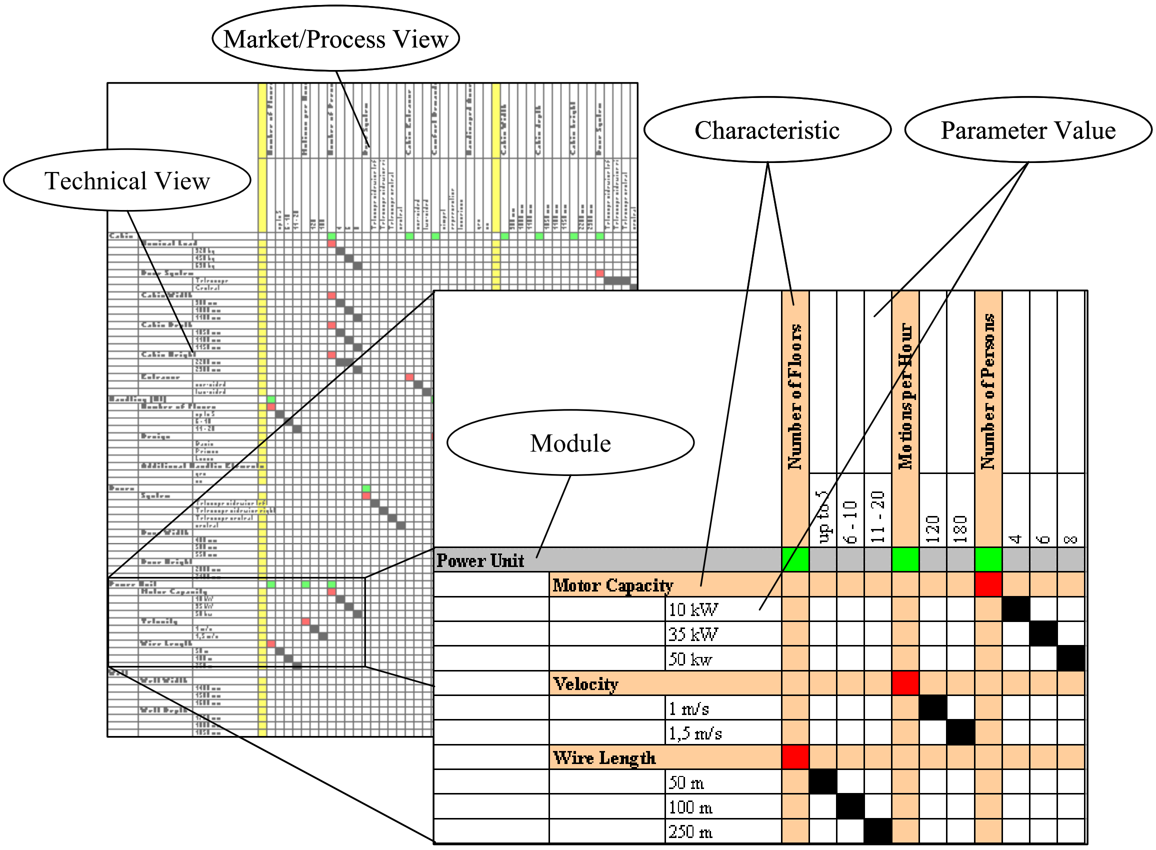

Figure 5. Correlation-matrix.

Additionally, both compatibility matrices are defined: one for the combinations of customer demands offered in the market and one for the combinations of technical properties that may be engineered. As mentioned before, this two matrices give an impression of the external and internal product variety. Figure 6 shows the compatibilities between the properties of the module "power unit". Based on this compatibility-matrix, ten different variants can be calculated for the module "power unit". If the parameter values "10 kW" and "35 kW" from the characteristic "motor capacity" would be deleted, the internal variety could be reduced to six variants.

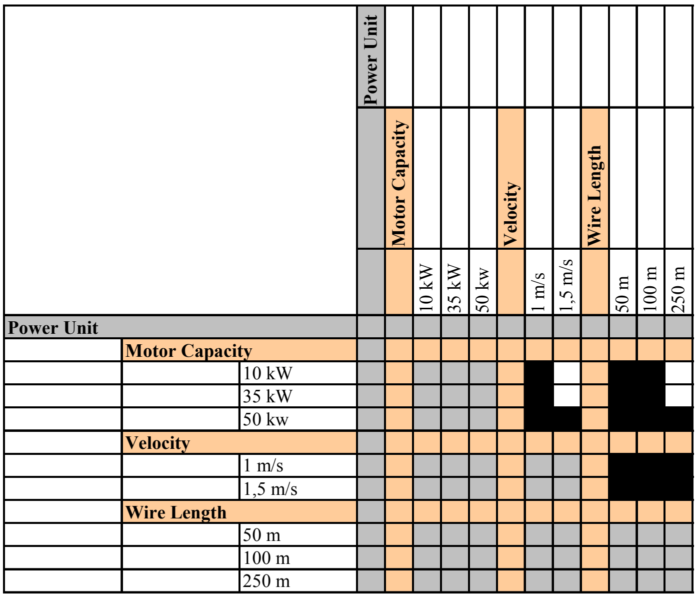

Figure 6. Compatibility-matrix of module “power unit”.

Considering the impact of this decision on the customer characteristic “number of persons” (Figure 5), it becomes obvious to reduce the motor variety to the capacity of “50kW”. In fact this variant fulfills all requirements. The ajusted matrices are shown in Figure 7. In the correlation-matrix (Figure 7, right) there is no more correlation between the parameter values of the characteristic “number of persons” and the parameter value “50 kW” of the characteristic “motor capacity”. In fact the characteristic “number of persons” do not cause any variety in the module “power unit”.

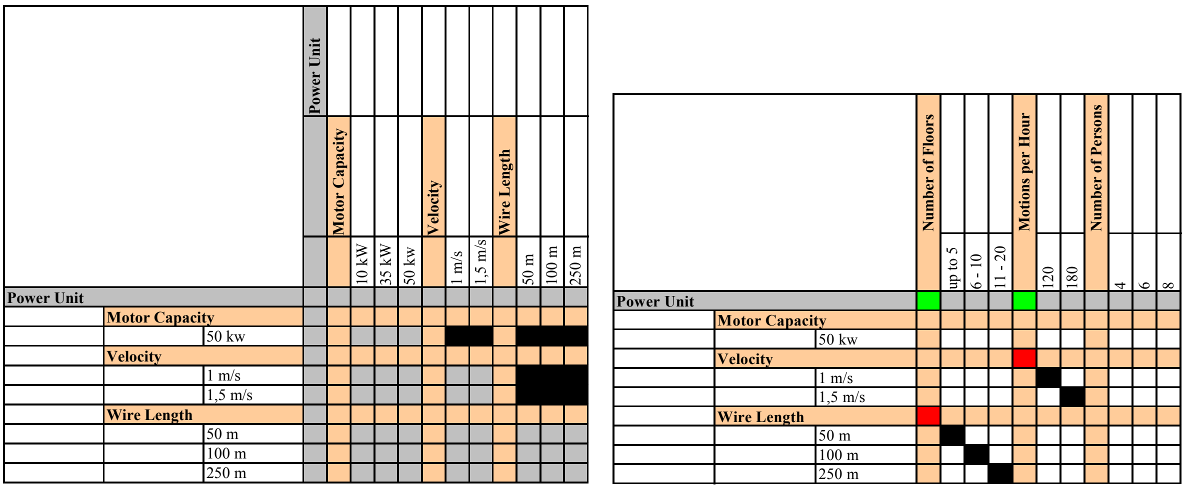

Figure 7. Optimised compatibility- and correlation-matrix.

The internal variety of the module “power unit” is reduced from ten to six internal variants. Hereby the external variety is not affected. This is achieved by using the same motor capacity for different number of persons.

Now, this proposal has to be verified. On the one hand the complexity that has to be managed in business processes is reduced and will result in lower process costs. On the other hand the high capacity power unit is much more expensive and will cause higher material costs. The reduction of the internal variety leads to a simplification of the business processes and permits to execute an “economy of scale” for the power unit.

5. Conclusion

The matrix system represents an easy-to-understand and easy-to-use way to describe knowledge concerning the modularisation and structuring of product families. Due to the flexibility of the proposed approach, it is possible to combine and apply existing methods (MFD, MPA, …) with the methodology for specific aspects of the product modularisation and product structuring process.

Considering properties containing customer specific characteristics as well as business process specific characteristics, a wide range of factors can be taken into account during the product structuring - already in the early stages of the engineering design process.

The proposed approach has already been verified in projects in industry. But further verification has still to be done in the context of the national project PiOPS (Process Integrated Optimisation of Product Structures) at the Swiss Federal Institute of Technology Zurich.

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