THE K- & V-MATRIX-METHOD IN COMPARISON WITH MATRIX-BASED METHODS SUPPORTING MODULAR PRODUCT FAMILY ARCHITECTURES

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Abstract

Over the last years, the product design literature has proposed many structuring approaches for modular product families. In many of these methods matrices have been used to represent different aspects supporting product structuring [6]. In this paper, four main methodologies are compared with the K- & V-Matrix, a method developed at the ETH Zurich. The aim of this paper is first to show the context, which the methods are used in, and second, to examine the possibility of using the K- & V-Matrix in a complementing way the other methods. The results show that the K- & V-Matrix can be theoretically combined with the other methods. A verification in industry has still to be done.

1 Introduction

In the last decade, many factors have changed in the enterprise-environment due to the diversification of the market demand. Global competition, increasing functionality of products, shorter innovation cycles, environmental standards are only some of these factors. Enterprises react to the changing situation by offering an increasing number of variants of existing products. Often, the internal product complexity is augmented with specific modules without real advantages for the product variety. This usually causes high costs and generates only marginal gains. Moreover, the internal product complexity frequently causes an increasing number of dependencies between single modules. These dependencies or rules make the product-configuration process more complicated for vendors and customers and is more difficult to support with IT-software.

A proven valuable attempt is not to deal with short-term measures like designing very customized modules, but to consider the eventual customer requirements already in the first stages of the engineering design process. Through an early mapping of the customer needs to product characteristics and later to the product architecture, it is possible to design adequate product families. With a product family architecture, various product variants can be derived from a basic product design, satisfying a spectrum of customer needs. Furthermore a product family architecture provides a generic structure to capture and utilize commonality and at the same time it provides some degree of freedom for the specific product customisation [4].

2 Methods for the Design of Modular Product Architecture

Although the effects of commonalization and standardisation of modules and parts are con–ceptually obvious, the assessment and the optimisation of their degrees are difficult, due to the complexity and uncertainty of a product family. This challenge has led design research to deal with the problems of designing product variety [5].

In the last decade, several approaches for the design of modular product family architectures have been described in the product design literature. Many of these approaches emphasise on different aspects, in order to achieve a modular product architecture, e.g.:

- commonality matrices or indices
- mathematical concepts
- functional product structure
- model based approaches to deal with product families
- integration of modules, based on the evaluation of enterprise-internal and enterprise–external factors.

This list gives an idea of the variety of methods. Some partial overviews about the research on modular product family architectures can be found in: [4], [7], [8], [9] and [11].

Some approaches proposing modular product family architectures use matrices as a represen–tation form to support the design team make decisions about the product variety. This paper focuses on four main methodologies for the design of modular product architectures and compares these matrix-based methods with the K- & V-Matrix. The aim of this contribution is to focus on the context of the methods and their position in the engineering design process.

2.1 The Advantages of the Matrix Representation Form

The matrix representation allows the comparison of two points of view or different aspects of a product. The systematic description of different aspects in the row and column headings is easy to understand and gives an overview about the related aspects. In fact, matrices are useful in systems modelling because they can represent the presence or absence of a relationship between pairs of elements. A major advantage of the matrix over the graphical representation is in its compactness and ability to provide a systematic mapping among system elements that is clear and easy to read regardless of size [1].

2.2 Quality Function Deployment (QFD)

Quality Function Deployment is one of the most popular matrix-based methods. Although it is not properly a method for the design of modular product families, QFD is often used as a starting point for other methods (see figure 2), for example Design for Variety (section 2.3) and Modular Function Deployment (section 2.4).

QFD is a powerful methodology and is based on four matrices (four Houses of Quality (HoQ)) for relating customer requirements, functional specifications, product design and process characteristics. Especially the first House of Quality, describing the mapping between customer needs and functional requirements, is often used in the context of other methods (e.g. the above mentioned methods).

The main advantage of the method is the systematic consideration of the requirements of the enterprise-external and internal groups of interest like: customers, suppliers or the manufacturing and design department. QFD guides design teams in achieving the integration of all requirements. Engineers can further benefit from a quantitative methodology, supporting the activities of the engineering design process [13].

2.3 Design for Variety (DfV)

Martin and Ishii presented an approach based on the assessment of indices to reduce the impact of variety on the life-cycle costs. Among other things the approach suggests the use of the so-called Coupling Index (CI), that represents the internal correlations between pairs of components [8]. The components are shown in the heading row and column of a square matrix. The Coupling Index results in the sum of the specifications (correlations) of a single component, described in the matrix fields.

The evaluation of the Coupling Index (CI) helps design teams make decisions on the way to rearrange the mapping between the physical components as well as the way to define the interfaces between them. This way, it is possible to develop a decoupled architecture that requires less design effort for follow-on products. A detailed description can be found in [8].

2.4 Modular Function Deployment (MFD)

Modular Function Deployment (MFD) is an approach which aims at achieving a modularisation complying to both the company expected improvements and environmental product drivers [10]. The core element of the method is the Module-Indication-Matrix (MIM). The heading row of the matrix represents the technical solutions of the future product family, also called sub-functions. In the heading column, the so-called module drivers are listed. The module drivers, found along the entire product life-cycle, are for example design related requirements, variance related requests, production and quality needs as well as purchasing and service related requirements. The MIM represents the correlations and the rate of correlation between the module drivers and the sub-functions.

Based on the correlation values, an heuristic evaluation is done, in order to generate and assess alternative product family architectures. The detailed procedure is presented in [10].

2.5 Modular Product Families (MPF)

Otto and his research team presented an approach for a product family architecting process [11]. This approach suggests the decomposition of the product family in a function structure as proposed in [12]. Every single function of the whole product family are listed in the heading column of the so-called Modularity Matrix (MM). The heading row is built by every single product in the product family.

The matrix enables design teams to recognise both product and product family concerns, in order to define common and unique modules in the product family. Thus, the matrix allows design teams to consider different partitioning schemes for each product architecture and for the whole product family [11].

3 Description of the K- & V-Matrix-Method

The K- & V-Matrix-methodology has been developed at the Centre of Product Development of the ETH Zurich and is based on two kinds of matrices:

- the K-Matrix (configuration matrix, "***K****onfigurationsmatrix*" in German)
- the V-Matrix (compatibility matrix, *"****V****erträglichkeitsmatrix"* in German).

The methodology allows to represent and manage a major part of the configuration knowledge generated for example during the engineering design process. The matrix-based methodology and the related IT-tool provide a useful support for analysing and structuring product variety emphasising on aspects about the configuration. Although an overview is given in the next sections, a detailed description of the method and its limitations can be found in [2] and [3]. An example is presented in [15].

3.1 The "K-Matrix"

The K-Matrix represents two views: a functional and a technical description of the product. The functional view describes the product with customer relevant properties (customer view, see figure 1), that are defined in the early stages of the product development process. The enterprise-internal, technical view (see figure 1) represents all variant modules in the product structure. The fields in the matrix describe the mapping between the functional and the enterprise-internal view.

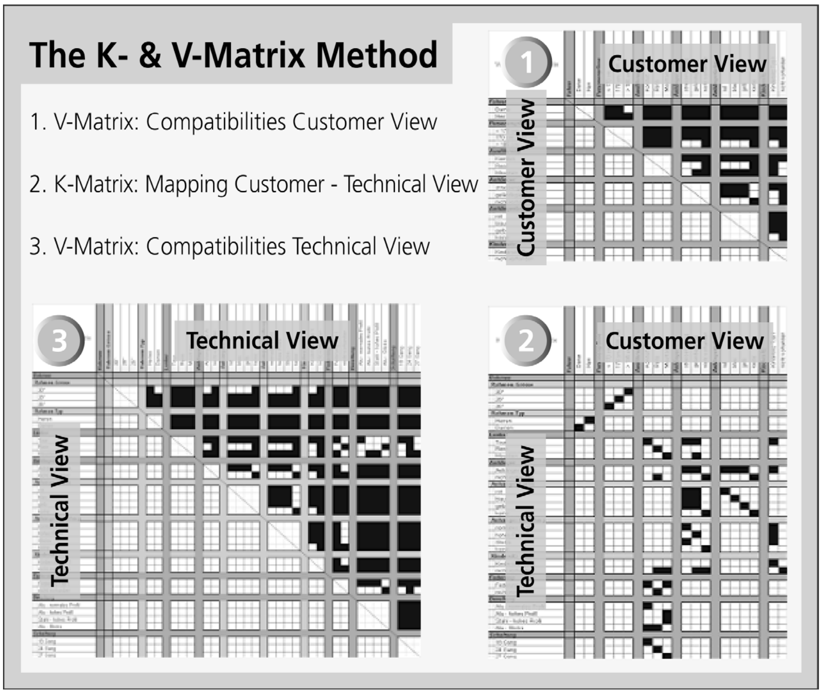

Figure 1. The structure of the K- & V-Matrix-method.

3.2 The "V-Matrix"

The V-Matrix defines the compatibilities of the properties with each other. The V-Matrix is square and its layout is as follows: the attributes and the respective values of a view are placed as row and column headings. Within the fields of the matrix it is possible to compare all values with each other, in order to define all possible combinations within the properties [2]. The V-Matrix can be set up for both views of the K-Matrix (see figure 1): for the customer view and for the technical view.

Recapitulating: the product views, the mapping between them as well as the compatibilities between product properties can be described and visualized by the K- & V-Matrix. During the configuration process, the customer or the vendor refers to the properties in the customer view, in order to specify his requirements. He makes creative decisions for generating a functionally complete and technically consistent product specification, interacting with the data of the K- & V-Matrix.

3.3 The Content of the K- & V-Matrix

As presented in the last two sections, the method is based on two common types of matrices, according to the classification in [6]:

- the inter-domain matrices, representing relationships between different element types and used in the QFD, MFD, MPF as well as in the K-Matrix
- the intra-domain matrices, representing relations between the same element types like in QFD (roof), DSM [1], DfV as well as in the V-Matrix.

The general difference between the mentioned methods and the K- & V-Matrix is given first by the content in the matrix fields and second by the context the method is used in. The permissible values in the matrices of the K- & V-Matrix-method are just “0” or “1”, in order to describe the existing or not existing relationship between two elements. This representation allows to simplify the content, so that it is easy to understand and to use, especially for employees with less technical skills. Thus, it is possible to use the data of the K- & V-Matrix in the context of the sales process. The method builds a communicative bridge between the sales and the engineering department and contains the major information used during the configuration process.

Usually, the K- & V-Matrix-method is set up during the late phases of the engineering design process or during reengineering activities, when structuring and configuration relevant activities take place. In order to compare the K- & V-Matrix with the other mentioned methodologies in chapter 2, we focus in the following section on the activities during the engineering design process.

4 The Positioning of the Methods in the Context of the Engineering Design Process

The methodologies listed in chapter 2 support design teams to solve problems related to the product architecture like commonality or modularisation. All these methods are characterised by two common stages during the engineering design process:

- the definition of a detailed functional structure (see figure 2, point 1).
- the structuring activities and the assessment of the concepts (see figure 2, point 2).

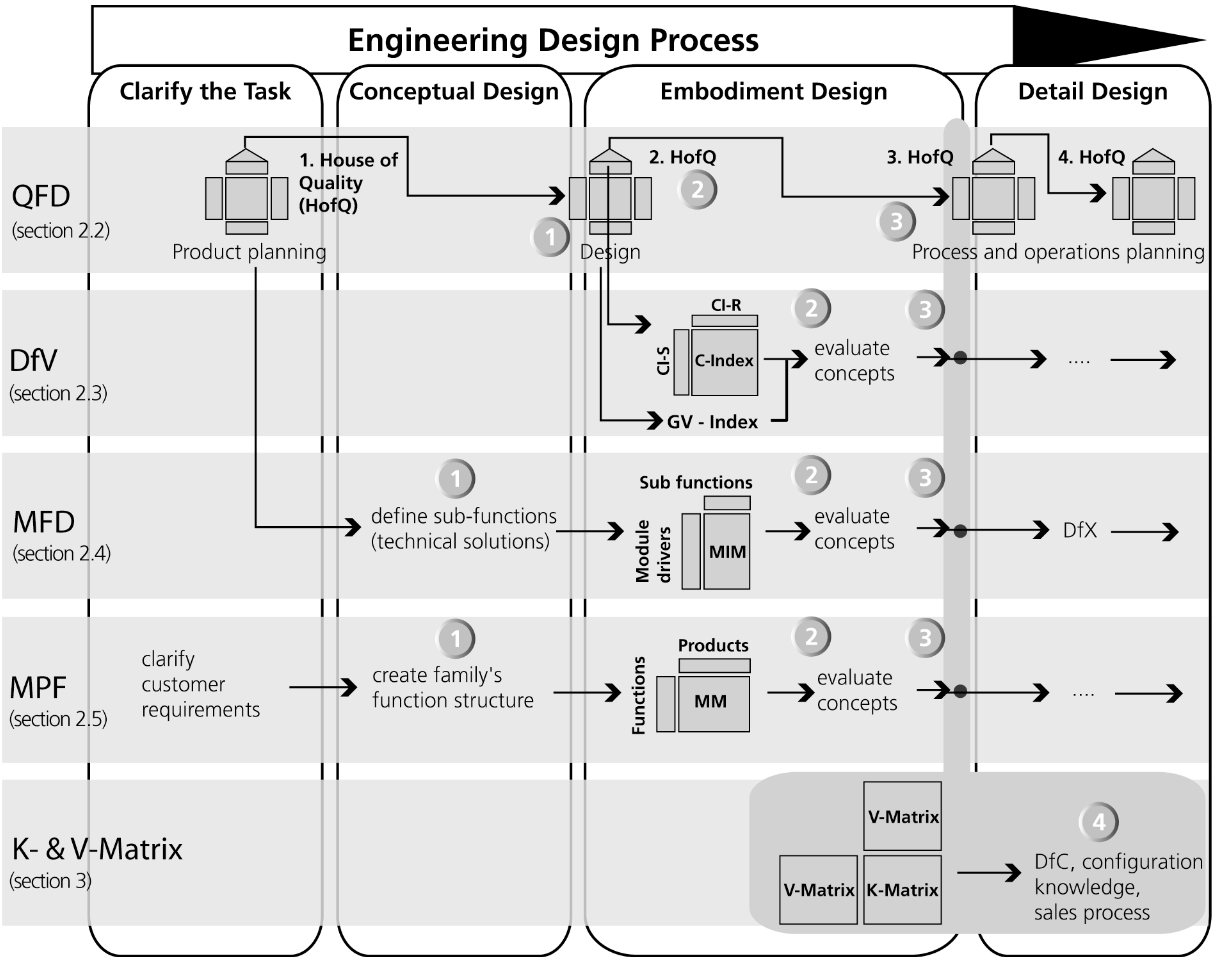

Figure 2. Flow of information through the methods during the engineering design process as described in [12]

The K- & V-Matrix does not support design teams in deciding about commonality and modularisation. In fact, the K- & V-Matrix usually represents only the product modules. During the embodiment design phase, the K- & V-Matrix can be set up only after the definition of the product architecture and the general design of the single modules. The general architecture design is a result of both, the second House of Quality (QFD) and the other methodologies (DfV, MFD and MPF). This way the K- & V-Matrix can be combined with the other methods, best at the end of the embodiment design process.

The technical view describes the variant modules defined during the design of the general product architecture (see figure 2, point 3). The functional view uses relevant properties for the customer (customer view, see figure 1), that are already defined in the planning phases of the innovation process. So it is possible to describe the K-Matrix. The generation of the product architecture makes it also possible to complete the description of the K- & V-Matrix with the definition of both V-Matrices. This way, an important part of the configuration knowledge can be explicitly represented already during the design process and not first by designing the configuration process.

The K- & V-Matrix provides design teams the following overview:

- first on the degree of fulfilment of the customer requirements with the designed modular components in the K-Matrix and
- second on the knowledge volume (e.g. number of rules and constraints) due to the exceptions and sub-optimal product family structure in the V-Matrix.

This qualitative overview can be used to analyse the product architecture e.g. in the detail design phase (see figure 2, point 4), in order to optimise the product structure for the configuration process. From this point of view the K- & V-Matrix also supports some important aspects of the Design for Configuration (DfC) as discussed in [14].

The combination of the methods in chapter 2 with the K- & V-Matrix supports:

- the design of modular product architecture,
- the consideration of aspects concerning the configuration during the design process,
- a systematic description of a major part of the configuration knowledge and
- a communicative bridge between the engineering and the sales department.

The combination of the methods on a conceptual level represents a complete tool for dealing with product structuring and configuration aspects. Thus, it is obvious that the K- & V-Matrix has a complementing role to the other methods in the engineering design process.

5 Conclusion

The methods supporting the design of modular product families focus on the aspects of the product structure and help design teams make decisions about standardisation and modularisation of the product family. Although modularisation is a valuable approach to deal with knowledge complexity in the configuration process, these methods do not describe explicitly configuration knowledge. The K- & V-Matrix method supports the optimisation of the product architecture describing a major part of configuration knowledge. Furthermore the method supports the configuration process and builds a communicative bridge between the engineering and the sales department.

The combination of modular product family architectures and the K- & V-Matrix during the engineering design process has been presented on a conceptual level. A verification of this approach in the industrial praxis has to be done yet.

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