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MATRIX BASED METHOD FOR MAINTAINING CONFIGURATION KNOWLEDGE

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Abstract

Increasing needs of the customers require the companies to develop product families with enough variants to be able to stay in business and keep the customers satisfied. The need for increasing variants of products, require a systematic way of maintaining the modular product structures in order to generate the configuration knowledge necessary. This paper presents a method for maintaining the configuration rules, both for marketing and production simultaneously, and presents the concept of configuration matrices as part of the integrating factor of the company. The main purpose of this research is to build a method to enable a systematic configuration process by establishing the configuration models for the products. Next to the configuration process the configuration knowledge can be used to analyze the state of the product structure, active components and modules, and topics related to product lifecycle and operations management.

1 Introduction

As companies are generating more product variants and starting to execute the ideas of mass customization [Pine93], the effects can be seen all over the company. Product design is faced with increasing needs to develop variety into the products, production system needs to be rethought, and the after sales experience increase in spare parts. While economies of scale dominate the world of mass production, variety dominates the world of mass customization.

The problems from increasing the level of variety are for example the reduction in the volume of production lots, the increase of the design workload connected to the development of new product variants, and the explosion of inventories of purchased and semi-finished parts [Forza02]. Next to these factors the need for representing and maintaining the knowledge related to the different products increases heavily and careful management of configuration knowledge is an important issue [Salvador04]. As the variety of products increase the dependencies of the product structure increases as well and cause problems in handling the existing configuration knowledge. In complex systems modularity is often offered as the solution for managing complexity. As modularity solves many aspects of mass customization the aspect of configuration can help personnel to understand many characteristics needed from the organization and the product structure in order to deliver customer specific product individuals systematically. Configurability of the products enables companies to shift from build- to stock into build- to order environment. Products, their modularity, and systematic representation of configuration knowledge are of great importance in these situations. The purpose of this paper is to present matrix based method that has proven effective in the context of modular product structures. The aim of this method is to represent the existing configuration knowledge to be used as part of the configuration process as well as to be used to analyze many aspects of different parts of the company related to configuration knowledge.

2 Product configuration and configuration models

Product configuration defines a specific product for a specific customer order i.e. the customer structure based on customer specifications is established during the configuration process [Tiihonen99], [Peltonen98]. Thus, the configuration process defines the configuration i.e. the customer specific product structure of a specific individual product. Considering the customer, product configuration gives the freedom of selecting the most appropriate variant of the product from a set of predefined options. These options are then translated into the product structures, presented usually as a set of modules. The task of selecting appropriate modules is the simplest form of configuration task and in more sophisticated applications product configuration can be accomplished by selecting values of properties or by assigning values to parameters [Jorgensen01].

The product needs to be configurable, because during the sales process the suitable module variant needs to be selected in order to specify correct product structures [Lapinleimu00]. This selection process needs the configuration knowledge to work properly whether the process is automated by using configurators or executed manually. Modularity is often considered as the basis for configurability [Aarnio03], [Riitahuhta00], [Tiihonen99], [Lapinleimu00], [Pine93], and [Jorgensen01]. Modularity offer means to handle complexity of the product structure, thus combining components into larger groups considering the configurability of the created structure. The modularity of the product structure can be defined by using many aspects of the company's operations. Usually the decomposition of the product structure is done according to the production system in order to make the production as effective as possible [Lapinleimu00], [Erixon98], and [Tiihonen99]. Also marketing, after-sales, maintenance, product development, and purchasing has their side of the product structure as well. In the context of configuration the most suitable type of modularity is functional [Tiihonen99], [Riitahuhta00]. This is due to the fact that the dependencies between the modules and the options can be minimized. The problem is that the similarity between the production system and the product structure cannot be reached with this type of modularity. Even if the modules are created considering the configurability [Aarnio03] the customer specifications determine the use of certain modules in a product structures and often the customer specifications have dependencies between each other which make the systematic presentation of configuration knowledge even more important. As the variety of the products increase also the knowledge needed to handle increases as well. This product related knowledge is expressed via configuration models which need to be defined in order to establish configuration process. Configuration model is defined as follows:

- Configuration model specifies how to create an appropriate variant for a given order specification [Peltonen98]
- Configuration model defines a set of pre-designed components, rules on how these can be combined into valid product variants and rules on how to achieve the desired functions for a customer [Tiihonen98]
- Configuration model is an abstraction of the real world product family that is specifically meant for configuration purposes [Tiihonen98]
- Configuration model (termed product family model) can serve as a foundation for the configuration process because it has a set of open specifications, which have to be decided to configure an individual product [Jorgensen01]
- Configuration model (termed product model) is a logic structure that formally represents the type of product offered in terms of characteristics (commercial and technical) and constrains between the characteristics [Forza02]
- Configuration model (termed product model) sets the rules for dynamically building the product variant documentation starting from the specific needs of the customer [Forza02]

Thus, the configuration model is a systematic documentation of the configurable product which makes the configuration process possible. This paper will present one way of expressing this configuration knowledge in the context of modularized product.

2.1 Configuration management

Configuration management is defined to equal the management of product and service variants [Riitahuhta00]. Configuration management includes all the knowledge related to the management of configurable products and also the aspect of the entire product life-cycle. As the importance of configuration knowledge increases the pressure is on the product development to generate the needed configurability at an early stage [Riitahuhta00], [Aarnio03], and [Bongulielmi02]. As the configuration matrices represent the configuration knowledge needed, they are an important part of the configuration management and the configuration process.

3 Matrix presentations

Matrix presentations have been used widely in the area of modular product design. Most frequently the matrices are concerned with issues such as platform development and modularity of the product structure. In literature there are many methods that include matrix presentations such as MPA (Modular Product Architecture) [Dahmus01], MFD (Modular Function Deployment) [Erixon98], K- and V-Matrix method [Bongulielmi01], [Bongulielmi02], DSM (Design Structure Matrix) [Steward81] and Generic product design process [Ulrich00].

[Malmqvist02] defines the matrix-based product modelling method to be a presentation of some view of the product structure. [Malmqvist02] uses the expression P-DSM (Product modelling Design Structure Matrix) due to the similarity of the DSM [Steward81] method with the exception of concentrating only on the product view. The element level matrices are used to present relationships between components, or parts of a single product whereas the product level matrices are used to consider the relationship between different properties and different products in order to support for example platform strategies [Malmqvist02]. The element-level matrices (figure 1) can be divided into inter-domain and intra-domain matrices [Malmqvist02]. The inter-domain matrices include the same element types in rows and columns. In this type of matrix presentation the relations and/or dependencies of the same type of elements are presented. Intra-domain matrices have different element types in rows and columns and the relationships between different element types are presented [Malmqvist02]. As seen in figure 1, the product-level matrices include the entire product or system in rows and the columns include the product aspect i.e. the product level matrices found by [Malmqvist02] are of type intra-domain matrices. The classification of matrix-based product modelling method types is shown in figure 1 [Malmqvist02].

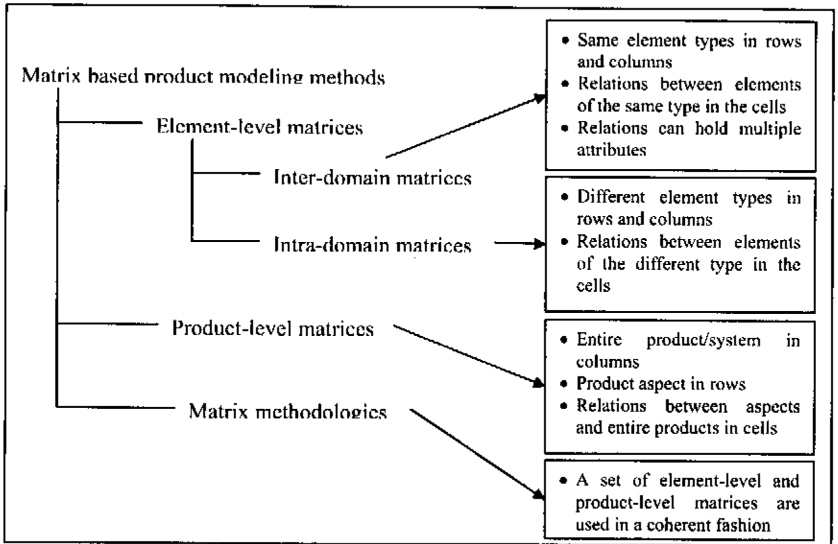

Figure 1. Classification of matrix based product modelling methods (Malmqvist 2002)

4 Configuration matrices

The purpose for configuration matrices is to present the configuration models of a company's products so that they can be maintained and even integrated with a configurator. The purpose of this research is not to build a configurator, but the aim is to develop a method that makes the presentation and maintenance of the configuration models possible in the context of modular product architectures and to evaluate the effects of well established configuration knowledge in the company. The purpose of this matrix presentation is to integrate the sales configurator rules with the engineering configuration rules to form a robust and simple way to maintain these rules. As [Malmqvist02] has divided the matrix presentations, the configuration matrices can be defined as P-DSMs since they have similarities with the DSM approach, but are concentrated on description of a product. Also the configuration matrices are of type element-level matrices and inter-domain matrices as they have same type of elements in rows and columns. Only difference is that as the entire product (module level) is defined in the configuration matrix next to the saleable options and the options are mapped against the modules in the matrix (figure 2). A part of configuration matrix is shown in figure 2.

Konfig Model	OPTION 1A	OPTION 1B	MODULE 1	MODULE 2	MODULE 3	OPTION 2A	OPTION 2B	OPTION 2C	MODULE 4	MODULE 5	OPTION 3A	OPTION 3B	MODULE 6	MODULE 7	MODULE 8	MODULE 9	MODULE 10	MODULE 11	MODULE 12	MODULE 13	MODULE 14
OPTION 1 A	o	x	x									x		x		x			x		
OPTION 1 B	x	o		x	x						x	x	x		x			x			
MODULE 1	x		o	x	x																
MODULE 2		x	x	o	x																
MODULE 3		x	x	x	o																
OPTION 2 A						o	x	x	x												
OPTION 2 B						x	o	x		x											
OPTION 2 C						x	x	o	x												
MODULE 4						x		x	o	x											
MODULE 5							x		x	o											
OPTION 3 A		x									o	x	x	x	x	x	x				
OPTION 3 B	x	x									x	o						x	x	x	x
MODULE 6		x									x		o	x	x	x	x				
MODULE 7	x										x		x	o	x	x	x				
MODULE 8		x									x		x	x	o	x	x				
MODULE 9	x										x		x	x	x	o	x				
MODULE 10											x		x	x	x	x	o				
MODULE 11		x										x						o	x	x	x
MODULE 12	x											x						x	o	x	x
MODULE 13												x						x	x	o	x
MODULE 14												x						x	x	x	o

Figure 2. Part of an example configuration matrix

As shown in the matrix (figure 2) the grey areas symbolize customer choices made during the selling process. The module level is the white areas of the matrix i.e. the modules depending on the choices made by the customer in order to generate customer specific product structures. The purpose of the matrix presentation is to present all the possible choices and related modules in order to generate valid and complete configurations. It is obviously imperative to have right kind of product structure, types of modules, and modularization in order make complete configurations and configuration models. The structures studied so far have been based on functional decomposition of the product i.e. the complexity of the configuration models rises from the dependencies between the saleable options.

The power of the matrix presentation is that all the configuration rules, both for production and sales can be presented simultaneously. Considering the configuration process and the generation of customer specific structures, the customer choices need to be connected to the module level. The critical part for the creation of the matrices is the experience of the personnel building them. The problem is that while configuration matrices present all the combinations of the possible modules, the rules can appear in different parts of the matrix. The reason for this is mainly the sequence of the choices in configuration matrices.

Considering figure 2, the sequence of the choices is predetermined in the context of the configurator. If a choice is isolated i.e. it has no dependencies with other choices, there is no difference at what point the selection will be made. Considering the routine manual configuration the building of the configurator will start from the selection of feature 1 (holds the options 1A and 1B). The example in figure 2 is concentrated on the selection made concerning the feature 3. When arriving to the feature 3, the dependencies between options (sales configurator) can be checked by moving upwards the matrix and studying the possible marks "x" between the options. There are no dependencies between the options in feature 2 and 3 i.e. the options of feature 2 has no dependencies with the options of feature 3. Feature 2 can be shifted considering the sequence of the features, because the lack of dependencies between other features, but it can also be at this point. In the example when considering the options 3A and 3B, there are dependencies between the options of feature 1 as follows:

Table 1. Possible choices

	Option 1A	Option 1B
Option 3A	Not possible	Possible
Option 3B	Possible	Possible

According to table 1, option 3A is not possible to select if there has been a selection of option 1A before. The reason for clear sequence between the selections of features is imperative since if the features 1 and 3 would be shifted around, it would be possible to select option 3A and option 1A to the same configuration. Even if the configuration matrix has a strict sequence between the selections of the features the configurator can be more flexible since the selection can be done virtually at any sequence because the configuration model holds all the knowledge that is needed. These dependencies between the features and their options make the configuration rules for marketing and sales.

Continuing with the example the next phase is to make the decision between selecting option 3A or 3B from the feature 3. After the selection the matrix shows all the dependencies between the modules and the options under consideration and options selected in the previous stages. Selecting the option 3A will suggest the selection of modules 6...10. At the previous stages the selection of options 1A and 2B has been made, for example. Considering the example in hand the selection 3A will lead to the selection of the following combination presented in table 2.

Table 2. Selection of modules

	Selected	Selection string (selected if...)
Module 6	No	option 3A AND 1B
Module 7	Yes	option 3A AND 1A
Module 8	No	option 3A AND 1B
Module 9	Yes	option 3A AND 1A
Module 10	Yes	option 3A AND (1A OR 1B)

The module 10 will be selected into the customer structure every time the option 3A is selected. There is no need for the mark "x" when the module will be included at all times considering a specific option. These dependencies cover the configuration rules for creating the customer specific product structures for production.

Next to the configuration rules the configuration matrices present the base machine which can be defined to the bottom of the configuration matrix (figure 3). The modules of the base machine have no dependencies between the modules and saleable options and these base modules are always included into the individual customer specific product derived from the modular system.

Konfig Model	OPTION 1 A	OPTION 1 B	MODULE 1	MODULE 2	MODULE 3	..	..	..	..	..	BASE MACHINE	MODULE n-8	MODULE n-7	MODULE n-6	MODULE n-5	MODULE n-4	MODULE n-3	MODULE n-2	MODULE n-1	MODULE n
OPTION 1 A	o	x	x																	
OPTION 1 B	x	o		x	x															
MODULE 1	x		o	x	x															
MODULE 2		x	x	o	x															
MODULE 3		x	x	x	o															
......						o														
......							o													
......								o												
......									o											
......										o										
BASE MACHINE											o									
MODULE n-8												o								
MODULE n-7													o							
MODULE n-6														o						
MODULE n-5															o					
MODULE n-4																o				
MODULE n-3																	o			
MODULE n-2																		o		
MODULE n-1																			o	
MODULE n																				o

Figure 3. The base machine in the configuration matrix

As this base machine is defined the benefits of this standard part of the product structure can be considered. This is actually the part where the functional modularity could be considered over modularity, since while this part of the structure does not vary at all it can be decomposed very freely. The matrix presentation of the product structure holds the generic product structure (all the modules possible), all the options needed to answer, the dependencies between options and modules, all the dependencies between options, and a clear sequence for manual configuration.

5 The role of configuration matrices in manufacturing company

The experiences of using the configuration matrices have been promising as the level of knowledge about the existing product structures has grown. The main benefit is the realization of the configuration knowledge i.e. the configuration rules and the generic product structure which enables the use of product configurators. The generic product structure that can be seen in the configuration matrices (figure 2 and 3) holds very valuable information for the company. This knowledge integrated with the ERP (Enterprise Resource Planning) or PDM (Product Data Management) databases of the company, enables the use of IT-technologies to generate various different analysis based on the generic product structures. For example the platforms of the company's products can be easily considered and defined as well as the current situation of valid parts and components in inventory.

The basis for pricing by using ERP/PDM databases and the configuration knowledge to generate feature based pricing has also been possible to generate. A systematic way of defining costs for different options is possible when establishing the combination of modules of a specific combination of options by using the configuration knowledge. These modules and their costs can then be automatically retrieved from the existing databases.

There are also benefits for design department next to the platform analysis in the form of defining currently valid parts, components or modules in order to support the standardization efforts systematically. For configuration management the configuration matrices offer the opportunity to give more insights into the systematic evaluation of the product lifecycle in the form of determining product options to be offered into the markets as well as presenting the active modules in respect to the volume generated by the different products to be able to consider the material management actions for individual parts and components.

One of the main benefits is the increased knowledge of the current situation of the level of modularity. Using the configuration matrices the product modularity can be evaluated and actions taken to define more appropriate types of modularity based on the current situation. As [Lehtonen03] proposes the next level from functional modularity is platform based modularity. The matrices can show the way due to the increased knowledge of the current situation (evaluate the base machine and the relationships between the option modules and base modules).

While the maintenance of configuration matrices take care of the evolution of the products there is less tacit knowledge related to configuration purposes in the organization as no configurations can be developed outside the knowledge of the configuration matrices.

Finally one of the main benefits for the development of configuration matrices has been the understanding of the need for systematic processes that has enough knowledge to understand the effects of their own actions in respect to the configuration process. The changes here are considered to include the changes from the customers into the specific product structures and also the changes from the design department on modules and components. This means that marketing needs to deliver appropriate specifications and the design department needs to deliver complete product designs in order to provide minimum amount of deviation into the routine processes.

6 Conclusions

Configuration matrices have been built as light as possible in order to generate all the needed information as simple as possible. The main purpose for the configuration matrices is to present all the options saleable at the moment and the connections between the combination of the selected options and the modules for production i.e. the configuration rules are established. This means that the generic structure for options is needed and also the generic product structures are imperative to have.

The idea of configuration matrices is that there is a connection between the modularity of the product structure and the matrices so that the matrices can be used to guide the product development to develop new types of platforms and types of modularity systematically as the knowledge of the current situation of the product structure and its modularity increases. The power of the configuration matrices is realized when integrating the generic product structures to local ERP or PDM systems. First this enables the automatic transfer of the configuration rules into the system and the tedious manual work is eliminated. Secondly, the integration enables the building for various pieces of software to analyze the structure and the current situation in production, marketing, and design department.

The main purpose of the method is to support the maintenance of the configuration knowledge and to offer means to analyze the current situation of the product structures in respect to the different parts of the company. The idea is that configuration matrices can be used as basis for manual configuration as well as basis for automatic configuration processes and configurators.

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