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DESIGN OF PRODUCT FAMILIES FOR CONFIGURATION

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Modelling Product Families, Configuration,

Abstract

In the paper different kinds of products are categorized according to the variety imposed to sales-delivery processes. The focus is on products with structural variants, which establish a product family. Four classes of varying systematics are presented and related to the types of product architectures. A brief review the configuration modelling means, which capture the relations and elements of a product family, and problems in configuration processes are presented. The relations between product structuring, configuration modelling and processes are analysed. The characteristics of a certain varying systematic necessitate the use of particular modelling method. The systematic and the method in turn dispose the characteristics of configuration and modelling process. Since the product family has to be economically feasible, product varying systematic and model have to be adapted to the chosen processes.

1 Introduction

Product family is a means for a company to manage variety, enhance commonality and reduce complexity in product portfolio and in sales delivery processes. The capability of fulfilling varying requirements of diverse customers with a number of variants from the same product family is an advantage. Commonality enables the economies of scale in product life-cycle processes, e.g. in part production, and reduced complexity endorses fast and reliable processes, especially in sales and delivery. A company is emphasizing between these characteristics of product families, when it has a certain approach to configuration.

Traditionally, four different product types with different kinds of varying attributes in the product structure are presented [Schomburg, 1980]:

- Standard products
- Standard products with variants defined by the company
- Standard products with variants defined by the customer
- One-of-a-kind product

Three generic business approaches are related to the above categorization of products and to the production volume. These are serial (mass) production, customisation by applying configuration, and developing engineered to order products (see figure 1).

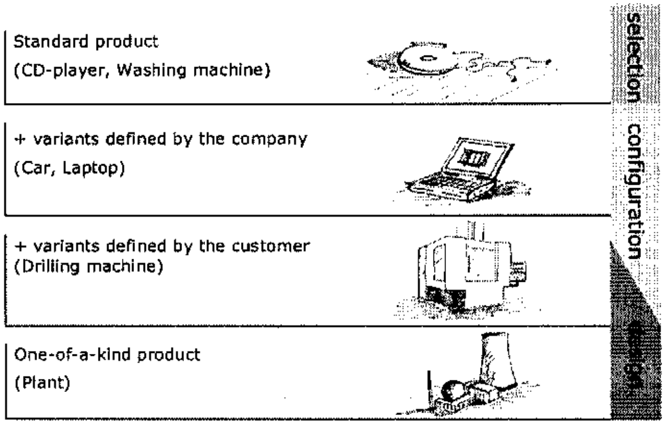

Figure 1: Types of products and the relation to the configuration

Choosing product and process type is not only a decision for product development, because with the selection a company is committing to certain means for pursue business benefits. These benefits have to be measured in generic terms, like time and costs. In order to transform the advantages of a product family as company wide benefits, many related aspects have to be coordinated. Apart from the design of the product family, a company has to align processes and organisations to the chosen strategy. The decisions made about product structure and the chosen modelling methods as well as the approach both in the development and the execution of processes dictate the resulting benefits.

As a standard product may be an individual of a product family, a one-of-a-kind product is not an individual of a product family. In this paper we concentrate on product families, which are composed by the standard products with variants. As visible in the figure above, a company has an approach to configurable products either from standard or one-of-a-kind products. We study the product structuring, configuration modelling and configuration process aspects of the product families.

2 The aspects of product families and configuration

Product family design is a process composed of the activities that develop and document product structures and the related configuration knowledge. For instance, product family architecture, modules and configuration knowledge have to be defined and documented as well as the order transaction, support processes and the organisation. Often, the support processes and organisations emerge as an extra expense to a company.

At the same time another issue, the configuring approach, is being defined including the business case and processes for the configuring organisation. The design of product family has an effect on how configuring is encountered by the organisations responsible for the sales-delivery process. Thus, the development has an effect on three different areas: product structures, configuration model and business approach. In practise, these three have to be balanced and aligned in order to gain a successful implementation.

2.1 Product structuring

Product architecture is a common structure for each of the configurations and it represents two kinds of generic relations. Firstly, it specifies the varying, changeable elements from the constant, fixed elements. Secondly, product architecture represents how different kinds of structures in different domains are interrelated. For instance, a product family has a generic function and part structures, whose relation is an aspect of product architecture. Product architecture has numerous effects to product life cycle, e.g. it defines the point-of differentiation in the production process.

Economical rules and motives for product architecting have been presented in the literature. There the economies of scope have complemented the traditional manufacturing paradigm, where the idea of economics of scale has dominated [Pine1994]. In the economies of scope, the cost of variety is a motive to modularise the corresponding features and elements in product architecture and the cost of performance is a motive to integrate the corresponding architectural elements [Erens 1996].

A generic product structure is a subset of product architecture, because it itemizes the varying dimensions from the static, fixed dimensions in a product family. Both the varying and fixed dimension of product structure can take place in the types of elements in different domains, the attributes and numbers of elements as well as their mutual relations. Variety between configurations may be created with a number of varying systematics:

1. Varying the type of an element
2. Varying the number of similar elements
3. Varying the attribute of an element
4. Varying the (topological) relations of elements

Varying the type of an element may be regarded as a special case of varying their attributes, if the type is based on varying a specific attribute. In the former systematic an attribute typically gets discrete values, while in the latter systematic the values are continuous. In practise, many of the varying systematics may occur simultaneously in product architecture.

In the simplified example of a generic audio system structure (see figure 2), a number of loudspeakers and amplifiers are part of an audio system. Varying the type of an amplifier and varying the number of loudspeakers are the examples of the first and second varying systematics, respectively. Similarly, in with an optional element the number of element varies from zero to one and therefore it is a special case of the second varying systematic. CD player and tuner are optional elements in the audio system example. Varying the power ratings of loudspeakers and the output power of amplifiers denote the third varying systematic in the audio system example. The example does not contain the case of fourth varying systematic. However, the actual set-up of the system elements has an effect of the variety experienced by the customer. For instance, the layout of loudspeakers in the audio example has an effect on the sound quality, which is an attribute in a process or functional domain.

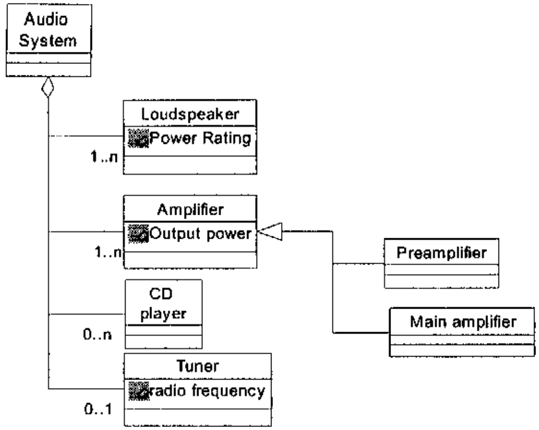

Figure 2. A generic structure for an audio system

Instantiating a specific part of structure from a generic product structure is not enough for defining the configurations completely. Therefore, also the design of varying dimensions (like modules, parameters and algorithms) has to be done as well as the means how to derive a specific structure defined. For instance, a generic bill of materials is not adequate for describing a configuration, if the modules and ways to combine them are left undefined.

Varying can be promoted with modularity, which is a characteristic of product family architecture. Modularity is a relational, diversiform issue that has many implications. Basically, it enables component swapping in a configuration and component sharing between configurations. Other categories of modularity are fabricate-to-fit, bus and sectional modularity [Ulrich and Tung 1991] as well mixed [Pine 1994] and stack modularity, which is a property of product assembly structure [Andreasen 1988]. A wobble pump is an example of stack modularity, because the tabular structure of the pump enables varying the functional properties along with the number of stacked bellows.

Table 1. Varied and fixed dimensions vs. the categories of modularity in product family architecture

Element type	Number of elements	Attribute of an element	Relations of elements	
				Component swapping
fixed		fixed		Component sharing
fixed				Fabricate to fit
			fixed	Bus modularity
				Sectional modularity
				Mixed modularity
fixed		fixed	fixed	Stack modularity

Labels: [shaded] = fixed [ ] = varied [ ] =undefined or both are possible

The dimensions in generic product structure are varied or fixed according to category of modularity, as shown in the table 1. For example, the element type is varied in component swapping, but fixed in component sharing. The degree of intended variety is highest with sectional and mixed modularity, where all the varying systematics may be used, which means the numbers of element and their types, attributes and relations can be different between configurations. Often with mixed modularity, even the relations of elements have no meaning and they are arbitrary. Sometimes, the mixing order has an effect on the end configuration, as it is in the case of mixing emulsions.

2.2 Configuration modelling

Configuration knowledge represents the mentioned dimensions and the conditions how to define a configuration within the dimensions. It is often captured in a configuration model, which is a means to communicate variation and commonality, with:

- a pre-defined common structure [elements, relations] and
- a pre-defined varying structure [elements, relations].

Apart from being capable to represent the structures with *part-of* and *kind-of* relations, configuration knowledge modelling methods may hold the means to represent other relations, like the combinability of elements in the structure with e.g. *constraints* and *rules*. Typically, a rule or a constraint excludes or includes varying elements so that they have to or cannot exist simultaneously in a configuration. Also, a rule or constraint may be a function (typically an equation or inequality), e.g. for a situation where the resource provided by one element must supersede the consumption of other elements. For instance, in the example of audio system the value of an attribute "output power" has to be in line with the value of an attribute "power rating" (see Fig. 1). In common words the amplifier has to match the loudspeakers.

Several ways to capture configuration knowledge have been suggested in the literature. Probably the most straightforward approach is to generalize the independent configuration selections into a Generic Bill of Material (GBOM) [Veen 1992]. Some apply selection tables [Heiob 1982] and matrices [Bongulielmi 2002], variant [Schuh and Tanner 1998] as well as AND-OR-trees. [Soininen et al. 1998] suggest concepts like abstract and concrete component types, three types of constraints, generalization and aggregation for modeling kind-of and part-of relations, respectively.

2.3 Configuration processes

Configuration is a means for defining and communicating the description of product individual from one business function to another. Generally, in human communication, there is a possibility of making errors. This possibility proliferates, as the information content and complexity increases, e.g. in configuration modelling. Thus, one of the aims of configuring products is to simplify and clarify the information exchange between different stakeholders.

This is often quite difficult when departments have to handle with different aspects of product in their own processes. The missing coordination of the exchange of information is especially evident when the information created in the beginning of the sales-delivery process enables the execution of single activities during the downstream processes. Typical mistakes are: wrong, outdated and incomplete information or representations of the product.

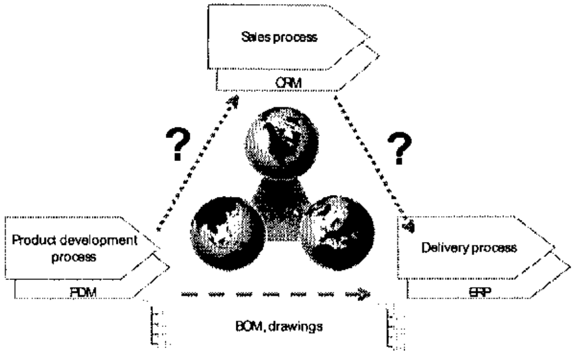

Figure 3. Exchange of information between the engineering, the sales and the production department

During the configuration process the sales department is interested about the varying dimension and about the characteristics of the product family. The production has to produce individual variants of the product family making a synthesis of the documentation of the engineering and the sales department. Often, this "synthesis", also called engineering configuration, is supported but not solved by an ERP-system (enterprise resource planning system). Even though the exchange of documentation between the engineering and the production can be supported with drawings and the bill of material (BOM), the exchange of information between the engineering and the sales department is often tedious. Along with cultural and organisational differences one of the major reasons is poor product modelling for the sales and the configuration process in the industry. The results are manifold:

- Configuration process depending from single vendors
- High number of wrong or incomplete configurations [Luhtala et al. 1994]
- Outdated and incomplete configuration model [Tiihonen et al. 1996]
- Increasing complexity of the product and the order transaction process during the product life cycle [Pulkkinen 2000]

3 Structuring and modelling for different kinds of products and processes

It is more appropriate to speak about a selection of a product than a configuration of a product in the case of standard products, which are made to stock with sales estimations and the variety is defined during the product development process.

Instead, standard products with variants defined by the company are characterised by a set of variable components. For the configuration process the company provides a range of values and the customer defines the values of the variables. In the case of standard products with variants defined by the customer, the customer does not only define a set of components by choosing some values. He has the chance to describe with own values some components in the product structures.

Likewise to the case of standard product, a one of a kind product is not configured, but engineered to order. Instead of configuring, each product is engineered to order by adaptive or variant design process, which follows the product development process beginning with the definition of the list of requirement, often called as a sales specification.

In this section we relate different structuring systematics, modelling methods and processes. An overview on the relation is in Figure 4. There, the products are categorized according to the fact what organisations are involved in sales-delivery process and what kind of IT-support is required. In the following this categorization is used.

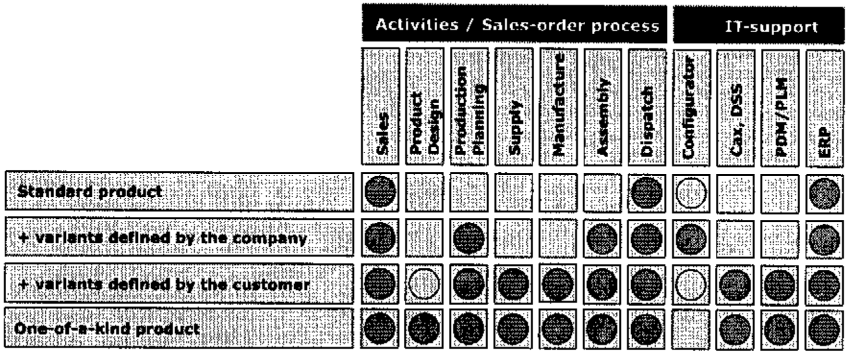

Figure 4. Products vs. processes and IT-support [Bonguliefmi 2003]

The modelling approach required with standard products is limited to the description of the fixed set of properties of every variant. Each set of properties is related to a fixed BOM and no complex modelling method is needed. The point-of-differentiation may be in the chosen stage of the production process, but as the products are made to stock according to sales estimates the common part in product structures is not utilised and the potential benefits are not attained, like commonality in information exchange is not experienced.

3.1 Structuring and modelling products with variants

The configuration process can be a part of the sales process, when a company specifies the variants. In this case, major organisational activities concentrate on the definition of the change process between the engineering and the sales department (see fig.3). The goal is to plan how to communicate the changes of the product from the engineering to the sales department. Beside this a second group of organisational activities concentrate on the flow of information between the sales department and the department involved in the engineering configuration. The goal is to guarantee correct and complete configurations.

When components have the characteristics defined by customer, parts are actually designed in the product (part) development process embedded in the sales-delivery process. In this kind of case, we speak about the partial configuration and the configuration process is partly done in the sales department and partly in the engineering department. The configuration activities may depend on the components and on the single orders. The organisational activities concentrate on the definition of the two possible processes. The goal is to clarify a procedure in the sales and in the order transaction process taking into account configuring and projecting activities. With one-of-a-kind product the point-of-differentiation is in the engineering and no commonalities between product individuals are harvested in sales-delivery. Instead, an often-used strategy with one-of-a-kind products is to compare the situation at hand to the previous sales specifications with similar requirements and revise the old document to the new context.

However, with this approach errors will be repeated and the context may be incompatible, which in many cases has led to problems in the delivery processes.

3.2 Product structuring vs. configuration modelling

In the case of standard products with variants defined by the company, configuring is usually based on varying the numbers or types of elements, whose attributes and relations are fixed. Thus, the suitable product architectures are often bus and stack modularity. If the company always defines the variants, an adequate modelling approach is to describe the product variety with properties, the components and the interrelations of single components. For instance, GBOM can represent varying the type of an element well.

If a company is delivering products with variants defined by the customer, the configuration may be based on any of the mentioned varying systematic. In this case, the product architecture can be mixed or even sectional modularity. Therefore, the inclusive/exclusive relations are often inadequate modelling concepts, because with theses relations it is difficult to express e.g. variety in layout. Also, the third systematic often requires functions that cannot be represented with the simplest methods. For instance, GBOM is not adequate for modelling the case of varying the topology of elements. Instead, logical rules, constraints or even selection algorithms have to be used to describe the configuration. In practise, either a design support system (DSS) has to be introduced or the handling of configurations has to be done manually, if the varying is based on varying the topology of elements.

However, usually the same relation can be represented with many ways. For instance, the mentioned constraint between loudspeakers and amplifiers can be represented in many levels of the generic structure. The exclusive/inclusive relations can be formulated between instances of components or component types. Also, a function can be written for calculating the compatibility of attribute values. If the aim is to fully define the customer specific sound quality even the surrounding environment and the topological relations have to be taken into account by an engineer or by using a DSS. With the more expressive methods, the generality of the model is higher than with the more simple methods.

The most expressive modelling methods, like knowledge based expert systems, have been developed to meet the requirements in cases where product has been previously engineered to order, has had an integral architecture and where it has been complicated to come up with a sales specification [Riitahuhta 1988, Tanskanen 1997]. This may have led to an induction: the most expressive tools are required when a company that has been previously engineered to order complex, integral, one-of-a-kind-products is approaching product families, configuration. According to our experience, this is not always true. In many cases companies have been able to specify the properties that require less expressive methods or simplify the constraints like in the above example of matching amplifiers with loudspeakers. However, they may be in such a concrete form that there will be problems in maintaining an ever-increasing number of simple rules.

3.3 Models vs. development, use and maintenance

In order to reduce the effort of implementation, configuration tools and methods should be easy to learn and to use. This must be taken into account when selecting the configuration modelling method. The deviation between existing and required capabilities of organisations making and using the model should be considered. Moreover it is essential to point out and to involve those people and organisations that will be executing the configuration tasks. The project leader has to ensure the commitment of both, on the level of the groups as well as on the management level of the involved departments.

Also, the number of deliveries that apply the configuration model is a significant issue. If these issues are neglected, the cost and time required in developing product family and applying it in configuration may exceed the savings in sales-delivery processes or increased income gained with the expansion of market share.

The needed levels of abstraction and details in the descriptions vary in different stages of the sales-delivery process. Usually, in the earlier stages the less detailed and more abstract descriptions are needed, while the accuracy of the description gradually increases during the process. The point-of-configuration in order-delivery process should be clearly identified in the definition of the configuration approach, like the point-of-differentiation in the definition of product architecture.

Often, when the modelling method's power of expression increases, the persistence of the model may increase. However, the complexity of the actual usually model proliferates. This may be a serious problem when there are different organisations developing, using and maintaining a configuration model. The idea of dispositional mechanisms [Olesen 1992] is valid, but only elevated in abstraction level, in designing product families and documenting the configuration knowledge. When organisations are having redundant, inconsistent structures and are ignorant of dispositions, the danger of making invalid configurations is high. When selecting the configuration modelling method, redundant structures should be eliminated as well as the means for keeping the structures consistent and up-to-date available.

4 Conclusions

We suggest that the development of a product family for configuration should start from defining the economical requirements for the corresponding processes and continue with defining the varying systematics and selecting the compatible modelling methods so that they meet the requirements. In developing a product family architecture the properties that vary in future configurations should be foreseen. A classification of the varying properties in alternative and optional properties has to be made and the systematic to enable the varying designed. These are the properties of product architecture and configuration model. Moreover, engineers should recognize the dispositional mechanisms between decisions in product family design and in following life-cycle activities, like sales, engineering and production. For instance, there should not exist a redundant varying property that can or will not be used in a configuration, nor sold or produced. Apart from being technically feasible, the product family has to be economically viable. The savings or profits from product individuals have to cover the expenses that are due to the development and maintenance of product family and corresponding configuration model.

Applying a certain varying systematic requires certain kinds of information exchange. If varying is based only on changing the type of an element or number of similar elements, simple method is an adequate one. The required power of expression increases with varying the attributes of elements. Concepts like parametric components have to be introduced, but they are sometimes poorly supported by IT-systems. By varying the topology of elements, design support systems are often needed. Communicating the common part of product family should be avoided and the information about selections should be minimized (to the least common denominator of mutually dependent selections). For example, in the customer view two interdependent selections should be generalized as a one selection, if possible.

Different modelling methods are capable to represent different varying systematics in different domains, i.e. their power of expression varies. In the selection of configuration modelling method, it should assessed how adequate is the method's power of expression in respect of the varying systematic. Sometimes abstracting and simplifying the relations can eliminate the need for more expressive modelling method. However, this may lead to the inconsistent structures or a model that cannot be maintained. In the worst cases, the cost of maintaining the configuration model may exceed the benefits or the inconsistent model may cause incorrect configurations that lead to losses in sales delivery process. In selecting the configuration tool, the capabilities of modelling method should be aligned to the needs in organisations that develop, use and maintain the tool as well as to the requirements from product structuring systematics.

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