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DEFINITION AND DESCRIPTION OF VARIABILITY IN CONCEPTUAL DESIGN OF MODULAR PRODUCT FAMILIES

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1. Introduction

Many companies face the need to offer a greater product variety to meet the individual customer requirements. Thereby one major problem is the increasing number of different subassemblies and parts, which have to be handled in the business processes within a company. The resulting complexity in the processes leads to higher costs, which affect negatively the competitiveness of such companies compared to mass product manufacturers.
An often-used measure to achieve a more cost-effective realisation of product variety is the development of structured modular product families. Thereby a product family is defined as a set of product variants with identical internal interfaces (technological, functional, physical), as proposed in [Erens 1996]. Purpose of this approach is to benefit from a larger extent of commonalities among the product variants (modules, subassemblies, parts – but also processes in production, logistics, etc.).
Due to the fact that 70% of the product costs are determined in early stages of the engineering design process [VDI 1991], it is important to define and describe a product family and its product structure respectively in an early process step of product design. Thus decisions and measures for assessing, controlling, avoiding and reducing the variability [Rathnow 1993] can be applied in an early process step of modular product family design.
Background of this contribution is a methodology for product structuring supporting the early stages of the design process [Sekolec 2003]. Keynote of this methodology is the definition of modular product families. Thereby unnecessary variability is identified and only the required variability is developed and offered in the market.

2. Variability of product structures

A product family consists of similar product variants. Each of these variants is characterised by its own product structure, whereby all of these product structures can be combined into one overall product structure of the appropriate product family, a so called variant parts list [DIN 2002] or order-neutral product structure. In the following the term product structure is used in the meaning of a variant parts list or an order-neutral product structure.
Considering such product structures two basic aspects of realising variability in these structures can be identified: the type of variation and the selection possibility. The basic variability of a product structure can be described by combination of the type of variation and the selection possibility [Montau 1996]. To derive a specific product variant from the product structure additional configuration rules and restrictions on the combination of components are required.

The type of variation includes the so called *part-variant* (Figure 1a), *structure-variant* (Figure 1b) and *quantity-variant* (Figure 1c). In addition to these three types of variation presented in [Montau 1996] a fourth type is introduced: the so-called *invariant* (Figure 1d).

- *Part-variant:* A bottom part in a product structure has different specifications and is generalised by one component type.
- *Structure-variant:* An upper part in a product structure has different structural relations to bottom parts. The consolidated relations represent a structure-variant.
- *Quantity-variant:* For a structural relation in a product structure different quantity values are allowed.
- *Invariant:* A bottom part in a product structure has only one specification.

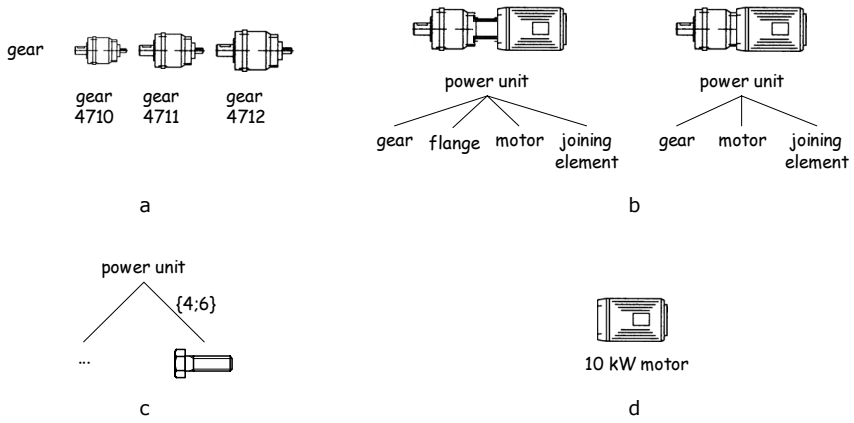

Figure 1. Type of variation: a) part-variant b) structure-variant c) quantity-variant d) invariant

The selection possibility includes the so-called *fix-variant ("Festvariante")*, *mandatory-variant ("Mussvariante")* and *discretionary-variant ("Kannvariante")*. It describes the consideration of a structural relationship in the product structure (Figure 2). The possibilities of selection are defined as follows:

- *Fix-variant:* No selection is necessary, because the structural relationship exists by default.
- *Mandatory-variant:* A selection is mandatory because the structural relationship is always required.
- *Discretionary-variant:* A selection is not mandatory because the structural relationship is optional.

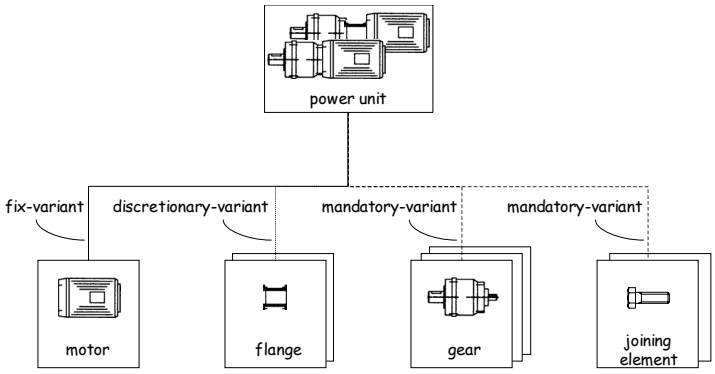

Figure 2. Selection possibility in a product structure

By combining the type of variation and the selection possibility (Figure 3) the basic variability of a product structure can be described.

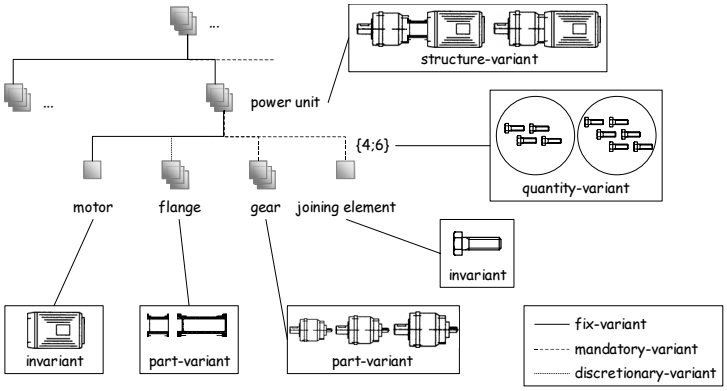

Figure 3. Variability of product structures

In Table 1 the different combination possibilities of the variation type and the selection possibility are illustrated and described in its resulting meaning.

Table 1. Combination possibilities of the two aspects of realising product structure variability

Description	Type of variation	Selection possibility
Invariant component which is contained in each product variant	Invariant	Fix-variant
Varying component from which exactly one variant has to be contained in a product variant	Part-variant	Mandatory-variant
	Structure-variant	Mandatory-variant
Varying quantity of a component whereby the component has to be contained in a product variant	Quantity-variant	Mandatory-variant
Invariant component that can be contained additionally in a product variant	Invariant	Discretionary-variant
Varying component from which exactly one variant can be contained in a product variant	Part-variant	Discretionary-variant
	Structure-variant	Discretionary-variant
Varying quantity of a component whereby no component has to be contained in a product variant	Quantity-variant	Discretionary-variant

3. Conceptual definition and description of variability

Customer and market requirements are the main cause of variability in the product family and in its product structure respectively. Normally the desired variability is very wide and has to be reduced during the design process by different measures like market segmentation, structuring of requirements, definition of performance spectra and functional variability as well as a design considering the possible variability. Purpose is to achieve the required variability of the modular product family by a product structure as standardised as possible with a large extent of commonalities among the product variants.

The basis for designing an adequate product structure is an accurate definition and description of the required product variability meeting the customer and market needs. This has to be accomplished already in the beginning of conceptual design where the level of detail of the modular product family is low (Figure 4). Based on the defined and described variability different measures for assessing, controlling, avoiding and reducing this variability can take place on a conceptual level. Thereby the conceptual definition of the variability should not restrict the effective implementation of the variety in the product structure, which is realised at a later stage. Thus the design of the product structure can be

established under consideration of the defined variability considering standardisation, re-use of components and building of part families as well as the optimisation of the degree of pre-assembly and further process requirements. Corresponding to the low level of detail in the beginning of conceptual design the definition of the variability should be accomplished in a very simple and intuitive but definite manner.

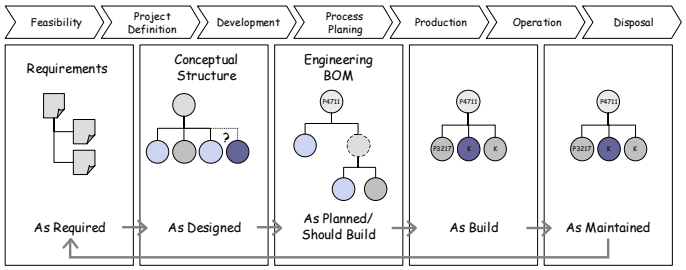

Figure 4. Product structure description in processes and life-cycle stages (according to [Eigner 2003])

The definition and description of product variability by characteristics and parameter values similar to object parameter lists [DIN 1992] is a possibility to achieve the requirements mentioned before. By characteristics and parameter values the basic variability of the modular product family can be defined on the one hand and on the other hand this variability can be described in a structured form. The definition and description of the variability takes place on module level. Thereby four types of characteristics are differed. These characteristic types are defined as follows:

- *Standard:*A characteristic contains exactly one parameter value. This parameter value occurs in each variant of the product family (Figure 5a)
- *Alternative:*A characteristic contains two or more parameter values. Thereby the parameter values are mutually exclusive. Exactly one of the parameter values occurs in each variant of the product family (Figure 5b)
- *Option:* A characteristic contains exactly two parameter values. Thereby one parameter value symbolises the realisation and the other the omission of the corresponding characteristic in a variant of the product family (Figure 5c)
- *Alternative-option:*A characteristic contains three or more parameter values. Thereby one parameter value symbolises the omission of the corresponding characteristic in a variant of the product family. From the other parameter values exactly one can be contained in a variant of the product family (Figure 5d)

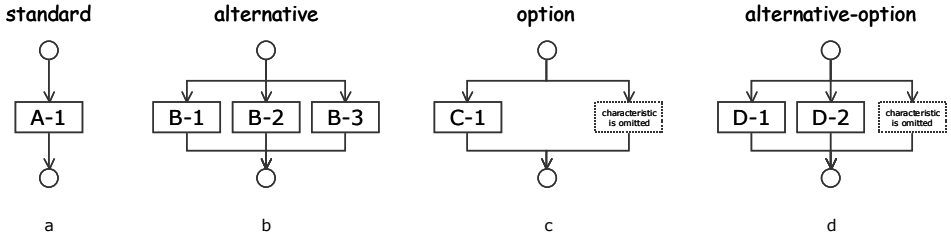

Figure 5. Characteristic types: a) standard, b) alternative, c) option, d) alternative-option (according to [Wüpping 1992])

By these different types of characteristics the variation possibilities of the product family and its modules respectively can be defined and described in a structured way. In Table 2 the characteristic types and the corresponding realisation alternatives of the variability in the product structure are compared. It is obvious that the variability definition does not restrict the variation type in the product

structure – only the possibility of selection is determined. Thus based on this description a product structure meeting further process requirements (shortening of lead time and cost) can be developed in detail design e.g. by means of DFX-methods.

Table 2. Characteristic types with the corresponding variation types and selection possibilities

Type of characteristic	Type of variation	Selection possibility
Standard	Invariant	Fix-variant
Alternative	Part-variant	Mandatory-variant
	Structure-variant	Mandatory-variant
	Quantity-variant	Mandatory-variant
Option	Invariant	Discretionary-variant
Alternative-option	Part-variant	Discretionary-variant
	Structure-variant	Discretionary-variant
	Quantity-variant	Discretionary-variant

In Figure 6 some types of characteristics are illustrated by means of a power unit product family. Thereby the variability of the modules motor, flange, gear and joining element is described. In consideration of additional configuration rules and restrictions on the combination of the parameter values, specific product variants could be described and determined.

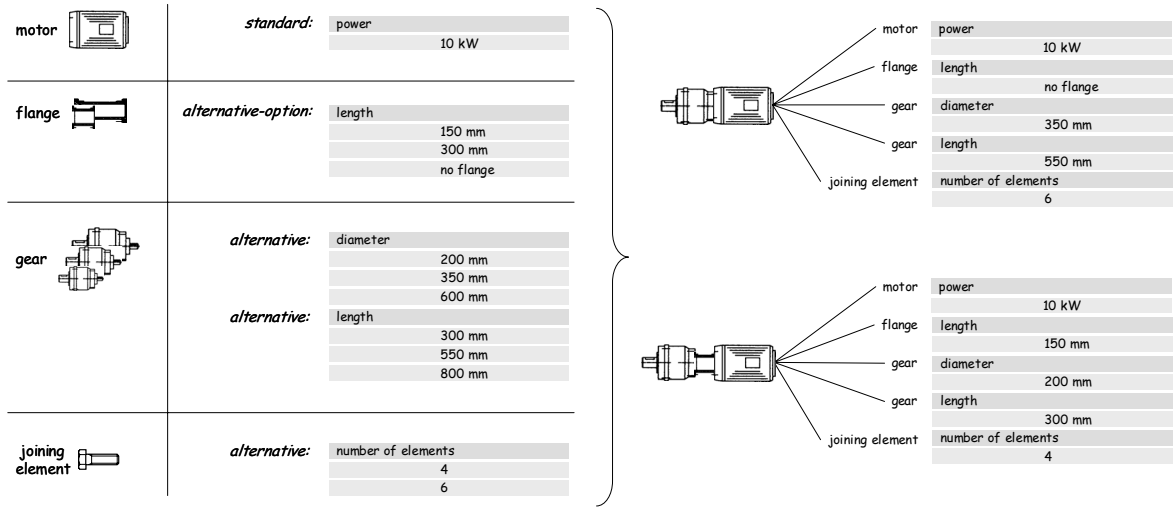

Figure 6. Definition and description of basic product family variability

4. Conclusion

The basis for designing an adequate product structure is an accurate definition and description of the required product variability meeting the customer and market needs. This definition and description has to be accomplished as early as possible in conceptual design. Based on this description different measures for reducing the desired variability during the design process can take place. Purpose is to achieve the relevant, external variability of the modular product family with a limited internal variability in the product and its product structure respectively. By considering further process requirements in the product structure the complexity in the business processes can be reduced additionally and cost savings can be achieved.

The definition and description of product variability in an early stage of the design process allows the assessing, controlling, avoiding and reducing of variability on a conceptual design level. Characteristics and parameter values offer a simple and intuitive way to define and describe the required product variability in conceptual design. Thereby different types of characteristics as well as the corresponding parameter values can accomplish the definition of the basic variability of the modular product family. Furthermore the variability is described in a structured and definite manner.
The conceptual definition of product variability by characteristics and parameter values does not restrict the effective implementation of the variety in the product structure at a later stage. Thus the variability description by characteristics and parameter values can be detailed and assessed continuously during the design process from the beginning up to the point where the first product structure is designed. Thereby the conceptual definition and description of the variability is used as a basis for the design of the product structure. Thus this approach constitutes a simple and effective approach in product structuring.

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