WDK WORKSHOP ON

PRODUCT STRUCTURING

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PRODUCT STRUCTURING IN DESIGN FOR MANUFACTURE

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ABSTRACT

This paper discusses product structuring with respect to manufacturing efficiency. If design for manufacture is to be performed with respect to all manufacturing costs, then product structuring is the most important mean for efficient manufacturing. The question of what a product structure really is addressed, and after that is the requirements from manufacturing on the product structure presented. Some design means (or techniques) are presented which can be used to physically realize manufacturing efficient product structures. The paper also discusses when and how efficient product structures are achieved during the design process and how DFM tools support this. It is concluded that traditional DFM hardly supports product structuring at all and therefore other tools must be used. The paper is ended by a discussion that implies that companies should develop their own DFM strategies which e.g. should tell which DFM tool to use with respect to product development project type.

1. INTRODUCTION

The objective of design for manufacture (DFM) is to consider manufacturing cost and efficiency during the design of products. The impact of design on manufacturing costs is a very important problem and have been dealt with since the early days of mass production. During the past twenty years the interest in DFM have increased a lot due to the increased competition. How to design products with respect to efficient manufacturing is well known and today a number of special DFM tools are available for companies who want to be assure of high manufacturability of their products.

A problem though is that throughout the history of design for manufacture the main efforts have been paid to rationalization of assembly (DFA) and fabrication of parts (DFF). This is also something that still is mirrored in the majority of DFM approaches used today. However, if the objective of design for manufacture is to rationalize the entire manufacturing process this implies that we should also look at for instance how to ease the production logistics by the means of design. Such a holistic approach to DFM demands that the entire product family or possibly product families should be regarded during design. This fact has also been pointed out many times (e.g. by Andreasen, 1983 and Stoll, 1986) but, at least in Swedish industry, there is a need for more consideration of manufacturing issues not only during detailed design but also during the structuring of products and product families.

This paper addresses the problem of product structuring as seen from manufacturing point of view. The paper starts with a discussion about what a product structure is. In Chapter 3 the relationships between product structures and manufacturing are addressed. Also some design means for creating effective structures from a manufacturing point of view is presented. Chapter 4 focuses on how the use of DFM methods and other DFM tools affects the design of a product and especially the structure of the product and product family. Finally some closing remarks is presented.

2. WHAT IS A PRODUCT STRUCTURE?

Before it is possible to discuss the importance of product structuring in design for manufacture it is necessary to define what a product structure is.

From a strictly theoretical standpoint it can be stated that the product structure is one of the basic design properties. As illustrated in figure 1 the properties of a product can be broken down into three classes (Hubka and Eder, 1988). First the external properties which correspond directly to the requirements put on the product. The external properties is realized by internal properties e.g. the strength of certain parts. The internal properties in turn are realized by a limited set of basic design properties i.e. dimensions, materials, tolerances, form, manufacturing methods and finally **structure.** Thus, there are many factors that decide the structure of a product and the manufacturability issues must be regarded in such a context. A problem is that design decisions regarding product structuring affect many of the product properties while the design of a part often only affects a limited set of the properties of the product. This may be one reason why traditional design for manufacture have been oriented towards detailed design so much. Design for manufaturing at structural levels becomes far more complicated than optimizing a given design. Design for manufacture with respect to a holistic view of manufacturing must be an integrated part of the design project.

But what is a product structure? A product has many structures dependant on what we study for the moment. For instance, we may consider a product as a collection of parts and components (assemblies). Therefore we have a spatial structure of parts and components i.e. a physical architecture continually called the **component structure**. The parts and components are linked together physically usually by form or friction.

We can also look at the product from a functional point of view and identify a **function structure**, i.e. we have a number of function-carriers that interacts with each other in order to perform the main functions of the product. These function-carriers are linked together by exchange of signals, materials or energy and does not have any physical property.

The perhaps most interesting issue in product structuring is when we investigate the relationship between the function structure and the component structure. For instance is the term modular product structure often used. But what is a modular product structure? This can be explained by studying the relations between functions and components. Ulrich and Tung (1991) have addressed this problem and came to the conclusion that product modularity is a relative property determined by:

1. Similarity between the component structure and the function structure of the design.
2. Minimization of incidental interactions between physical components.

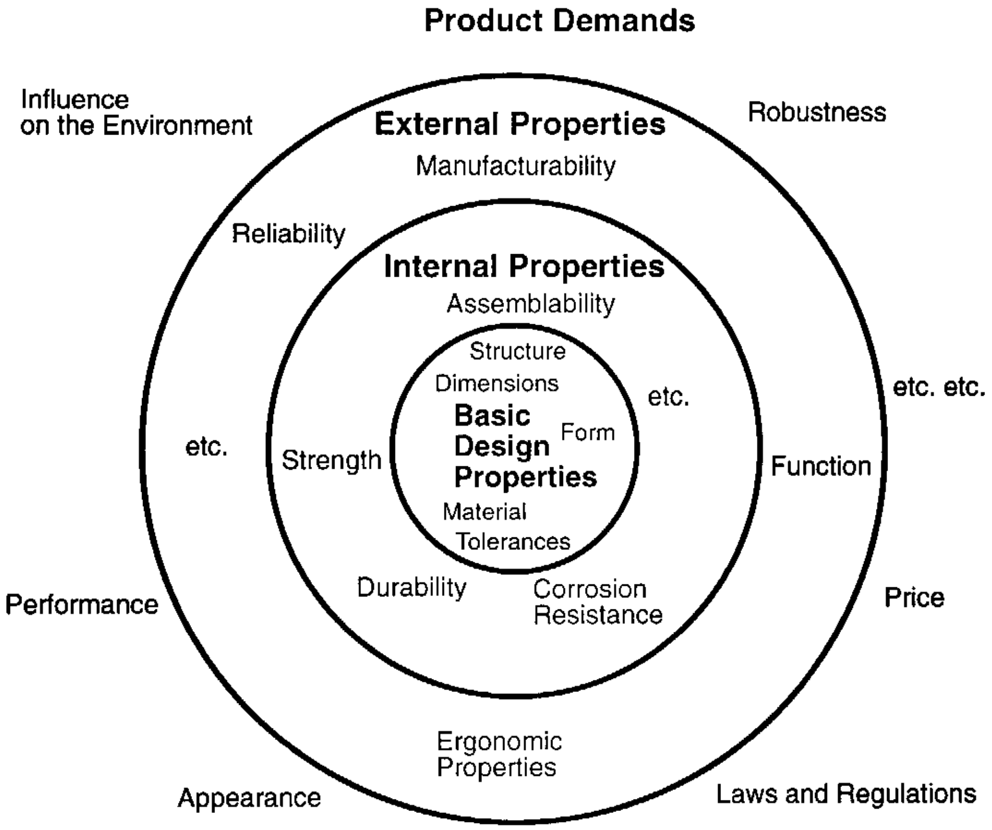


Figure 1. The relationships between different classes of product properties. (Partly from (Hubka and Eder, 1988))

The opposite structure to the modular structure is the integral structure. An integral structure is defined by a complex mapping between the functions and the components of the product. the complexity lies in that each function either is realized by a number of components or each component contributes to several functions. Thus, a structure of a product can also be described in terms of there is a one-to-one mapping or a complex mapping between functions and components, see figure 2. Ulrich (1992) denotes this structure as the **product architecture** which consists of:

1. The arrangements of functional elements.
2. The mapping from functional elements to physical components.
3. The specification of the interfaces between interacting components.

As will be described in the next chapter the product architecture has a significant influence on the possibility to achieve manufacturing efficient products.

This paper discusses product structuring as seen from manufacturing point of view. It must be emphasized that what finally determines the product architecture is a number of factors for instance: product change, product variety, component standardization, product performance, production process and product development management.

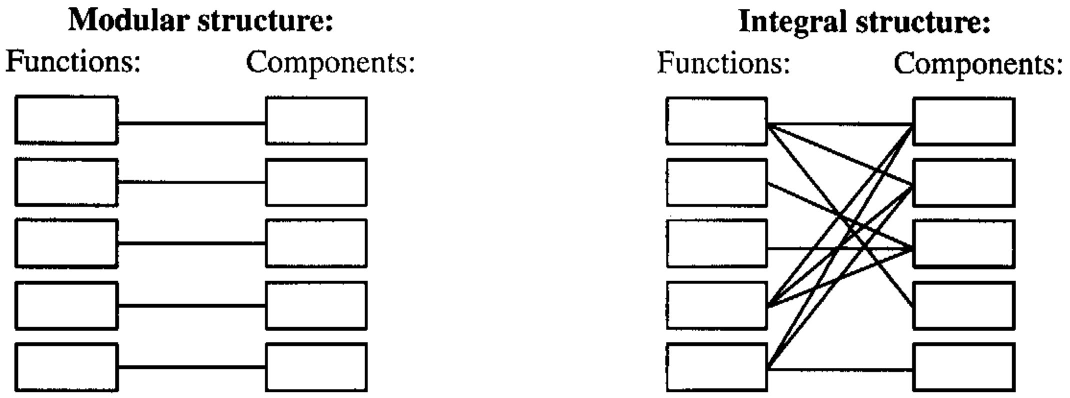


Figure 2. Modular versus integral products. A modular product shows more or less a one-to-one mapping between main functions and physical components. An integral product shows a complex mapping between functions and physical components. A function may be realized by two or more components and one component may contribute to two or more functions. Partly after Ulrich (1992).

3. PRODUCT STRUCTURING FROM MANUFACTURING POINT OF VIEW

The major question in design for manufacture is how to design a set of products (also with respect to future products) so they can be manufactured as efficiently as possible. This implies that it is necessary to know which characteristics of the design of a product family that determine the manufacturing cost. Below are the most important properties of a product family (as seen from manufacturing) listed:

- The product architecture.
- The component structure.
- No of variants and the commonality between these. (Not only physical commonality but also from e.g. assembly point of view)
- No of part types.
- Choice of material, form and other properties that determines the choice of fabrication processes.
- Detailed design of parts.

It is evident that the first four of these properties do have strong relations to the product structure.

From manufacturing point of view we want to produce the product variety of the company by the use of as few parts and processes as possible (Suzue and Kohdate, 1990). We also want to be able to structure the manufacturing system in an efficient way e.g. we want separate production lines for different components in order to ease planning and control and we want to be able to introduce variety as late as possible during the production in order to minimize inventories and need of flexibility (Witte, 1984; Mather, 1987) Late introduction of variety will also ease production planning and facilitate rationalization of the production of common parts and components. These wishes can be illustrated by a simple model of the production flow, see figure 3.

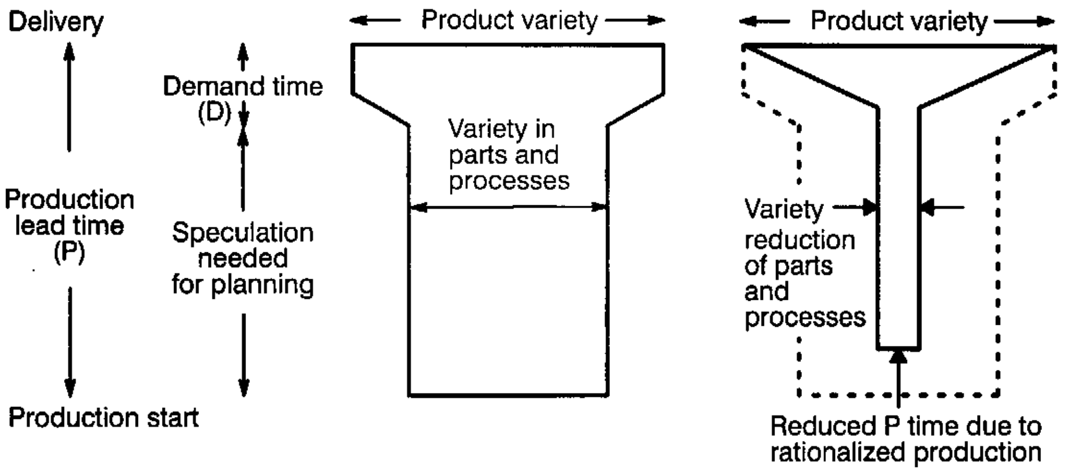


Figure 3 How part variety affects production logistics. Part variety reduction and late introduction of variety will ease planning, rationalize production and decrease inventories. Partly from (Mather, 1987).

The question is how these wishes or requirements from manufacturing can be realized by design? Some special tools to support this have been developed (e.g. Suzue and Kohdate, 1990; Janson, 1993; Reinders, 1993; Erixon et al, 1994) The basic means for variety reduction is company internal standardization i.e. delimitations of the allowed number of part types and component types and to make as much of the structure as possible common between all the product variants. The standardization can be conducted at different levels of the product structure. These examples illustrate this:

Limitation of the allowed number of part types, e.g. fasteners. This is a standardization effort which affects the lowest structure level. Efficient manufacturing of a number of product variants is not directly supported by this. The result is less parts to keep track of and possibly also a decreased number of manufacturing processes as well if the parts are manufactured in house. Decreased tooling cost in assembly is also a possible effect. An example of this type of standardization is the fastener variety reduction program at SAAB Automobile in Sweden. From 1988 to 1993 the number of types of fasteners used by SAAB were reduced with 43%.

Creating an integral structure by the use of components that contribute to many functions can actually be an effective mean for reducing the number of parts and part types in a product. This can be accomplished by the use of net-shape manufacturing methods e.g. injection molding or metal extrusion. Such processes make it possible to relatively easy produce parts with complex geometries.

Standardization of modules (modules as defined in Chapter 2). To make basic function units common for all or several product variants is perhaps the most effective internal standardization with respect to manufacturing. This type of standardization demands a modular product structure as described in Chapter 2. If the mapping between functions and components is complex is it very difficult or impossible to make a component common for several product variants. For instance is it difficult to use the mechanic part of a mechatronic product in other variants if the printed circuitboard is used as both a chassis for the mechanics and a part of the electronics. It would be better to minimize the interactions between electronics and mechanics if we want to be able to use e.g. the mechanics in other products too.

In this context is it necessary to mention the idea of **building-block-systems** BBS's. Building block systems is a system of modules, other components or parts which have been standardized and designed in such a manner that a number of (sometimes a very large number) of product variants can easily be produced by simply combining building-blocks. The nature of BBS's have been described and discussed by Borowski (1961) and a classification of building-block-systems are shown in figure 4. The basic idea of BBS's is **combination** as a mean to achieve variety.

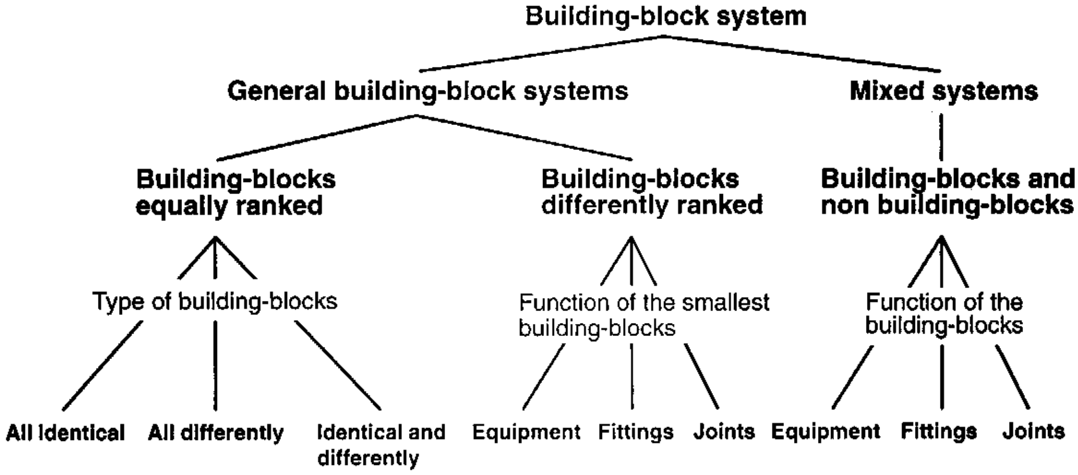


Figure 4. Overview of different principles for building-block systems, according to Borowski (1961).

If we look aside from the problematics of producing a number of product variants efficiently and only looks at the problem of producing one product (or module of a product) we will find that a modular product structure has benefits in that context too. A modular product makes it possible to treat the modules as sub-assemblies which gives opportunities to parallel assembly and short assembly lead time. However assembly can be rationalized by other structural means too. For instance is it useful to have a suitable base component to add parts on and to be able to assemble from above. Such requirements can be fulfilled by a suitable assembly oriented component structure. A good overview of assembly oriented component structures can be found in (Andreasen, 1983).

4. PRODUCT STRUCTURING AND THE USE OF DFM TOOLS

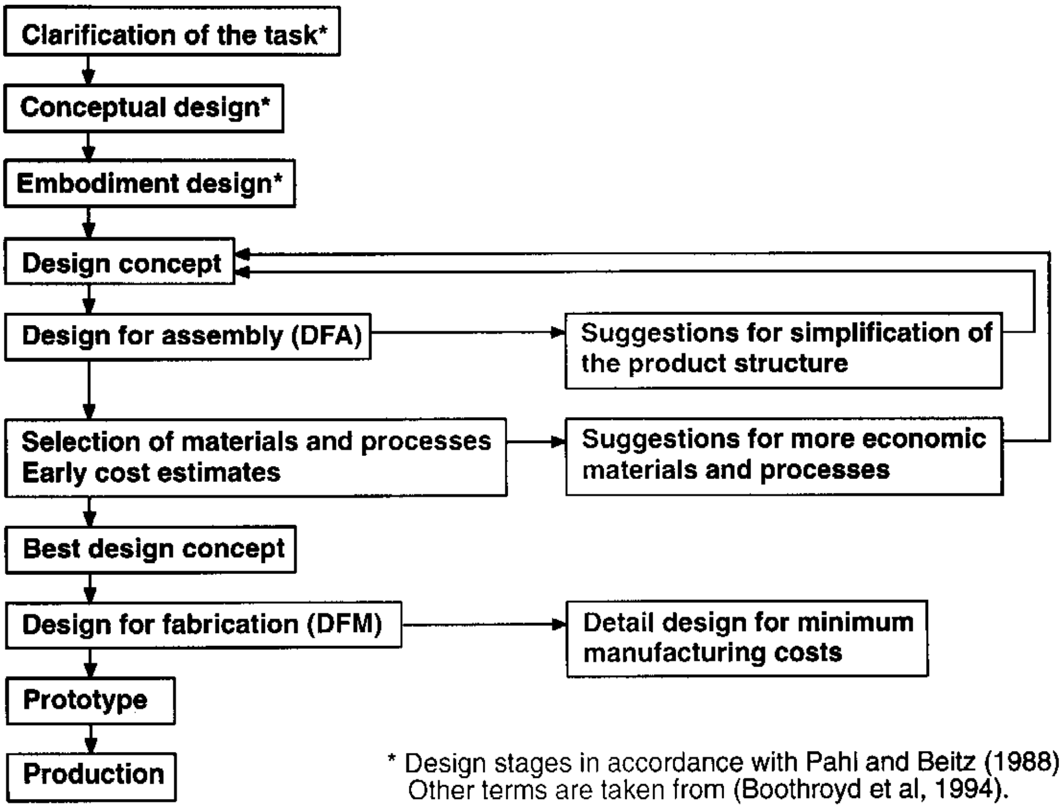
In Chapter 3 the relationships between properties of the product structure and manufacturing were discussed. The conclusion from this is that the designers should strive towards:

- Maximum commonality between product variants with respect to manufacturing processes.
- Late introduction of variety in the production flow and especially the assembly.
- Minimum number of part types.
- Assembly friendly component structures (suitable base component, stackable, few assembly directions etc.)

The question is how this best can be accomplished during product development. If the product design process is studied it is evident that the product structure is more or less determined during conceptual design and early embodiment design (Herbertsson, 1995). It can therefore be claimed that best way of achieving a good product structure is by the systematic development of several product concepts during conceptual design (Fabricius, 1994). If a given product concept and thus a given product structure is the starting-point for improvement towards the four goals presented above, the likelihood of ending up in a new concept will be much smaller than if we focus from the very beginning to develop a number of concepts.

In this context it could be interesting to compare two DFM approaches.

The first approach is taken from (Boothroyd et al, 1994) and represents the traditional DFMA techniques. The basic procedure to follow is presented in figure 5 together with some of the steps from the systematic design procedure of Pahl and Beitz (1988). The DFA and DFF analyses in the figure are based on the commercial softwares of BDI (Boothroyd-Dewhurst Inc.).



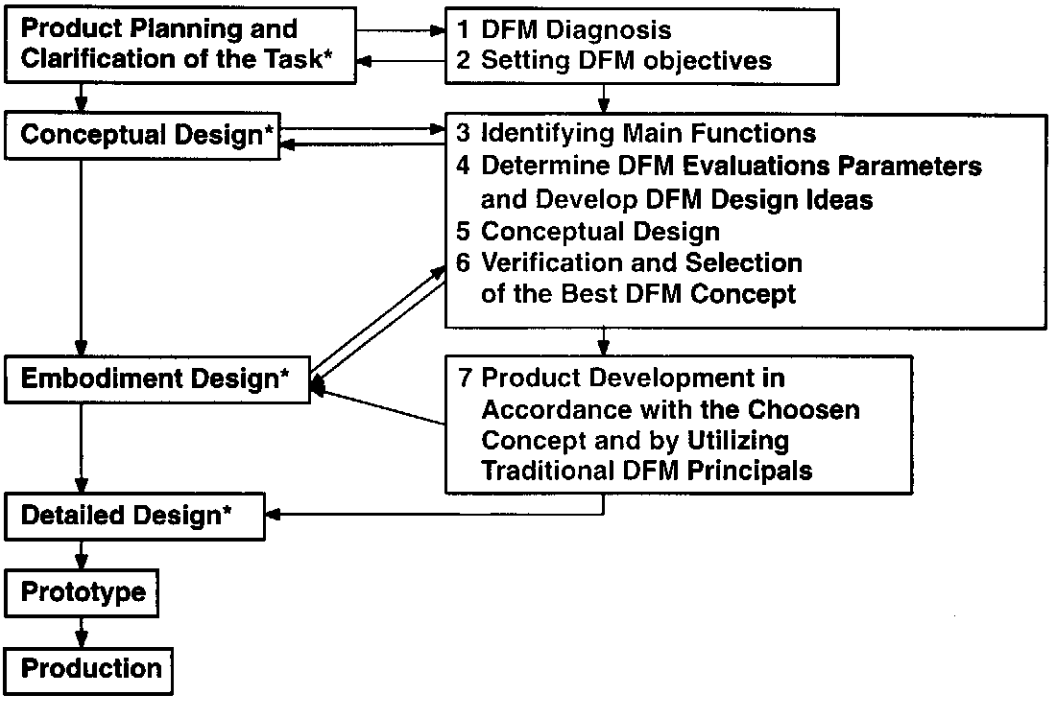
* Design stages in accordance with Pahl and Beitz (1988).
Other terms are taken from (Boothroyd et al, 1994).

Figure 5 How DFM should be conducted in the design process as proposed by Boothroyd et al (1994). Their proposal for how to conduct DFM has been combined with the steps of Pahl and Beitz (1988) systematic product design process.

The other DFM approach is based on the work of Fabricius (1994) and represents what could be said to be a completely different school. The approach is based on a "seven step procedure" aimed at helping the design team to consider manufacturability from the very start of the product design project and to create the best possible product concept from manufacturing point of view. In figure 6 the seven steps of the procedure are shown together with the systematic design approach of Pahl and Beitz (1988) for comparison.

A quick comparison of these two approaches gives at hand that (Fabricius, 1994) focus heavily on conceptual design while (Boothroyd, 1994) more or less focus on optimization of a given structure. If these two approaches are studied even more detailed with respect to some important DFM factors the result can be summarized as in table 1.

As can be seen in table 1 there are even more facts that underlines that Boothroyd's approach is most suitable for supporting DFM of existing structures and that Fabricius' approach is most suitable for developing a good conceptual design. These two approaches may therefore complement each other.



* Design phases of the systematic approach of Pahl and Beitz (1988).
Other terms are taken from (Fabricius, 1994).

Figure 6 How DFM is conducted in the design process in accordance with the procedure described by Fabricius (1994a, 1994b). The steps from the DFM procedure have been combined with steps from Pahl and Beitz (1988) systematic product design process for a comparison.

The use of DFM tools can also be looked upon in the context of all product development projects in a company. Wheelwright and Clark (1992) have classified the development projects of a company after degree of product and process change, see figure 7. As illustrated in the figure there is a direct correspondence between platform projects and the development of a new product structure. Therefore it can be assumed that a DFM approach as Fabricius (1994) is most suitable in these types of projects. On the other hand is many design projects in a company focused on enhancement or addition of a product variant to an existing family (platform). This means that Boothroyd's (1994) approach or other types of DFM tools are suitable for such derivative projects since the product structure more or less is fixed.

An implication of this is that companies probably must develop their own DFM strategies depending on e.g. the degree of product change in different projects. The strategy should tell what types of tools should be used in different types of development projects. If there is great possibility for both product and process change in a platform project then perhaps Fabricius' procedure (Fabricius, 1994) or the MFD (Modular Function Deployment) procedure (Erixon et al, 1994) is most suitable. And if the stucture is more or less fixed in a platform project maybe the VRP (Variety Reduction Program) (Suzue and Kohdate, 1990) is more suitable as a tool. In derivative projects with limited possibility to change the process and a fixed product concept the DFM strategy should be to exploit the benefits of the original platform idea and to conduct traditional DFM oriented towards fabrication and assembly.

Table 1.1 Comparison of two DFM approaches in relation to some essential characteristics.

	Approach 1 (Boothroyd et al, 1994)	**Approach 2** Fabricius (1994a,b)
Supports DFM strategically?	No	In a limited extent
Emphasizes benchmarking with respect to manufacturability?	No	Yes
Sets out DFM goals clearly?	No	Yes
Supports DFM during conceptual design?	To a very limited extent	Yes
Supports DFM during embodiment and detailed design?	Yes, by using software tools	To a very limited extent
Considers all the manufacturability determining product characteristics?	No, the focus is only on assembly and fabrication	Yes
How is manufacturability measured?	By direct assembly and fabrication costs	Several ways are suggested

5. SUMMARY AND SOME CONCLUDING REMARKS

This paper has emphasized that the structure of a product is determined by many factors since it is one of the basic design properties a designer work with. A product structure was defined as a function structure, a component structure and the mapping between these two structures. A one to one mapping was defined as a modular structure while a complex mapping was defined as an integral structure. The manufacturability of products is very much determined by the product structure especially if a great number of product variants have to be produced. Some design means for reducing the part and component variety were presented. It was stated that conceptual design is most important for achieving good product structures. Finally two DFM approaches were compared and discussed in this context. It was among other things found that one approach focused heavily on conceptual design while the other focused on optimization of a given structure with respect to fabrication of parts and assembly. This implies that different types of DFM tools should be used in platform projects and derivative projects. It could be a good idea to form a DFM strategy in the comany which should tell what DFM tool to use dependant on the circumstances.

The main conclusion of the paper is that if DFM is to be conducted with respect to all manufacturing costs then product structuring definitely is the most important issue to focus on.

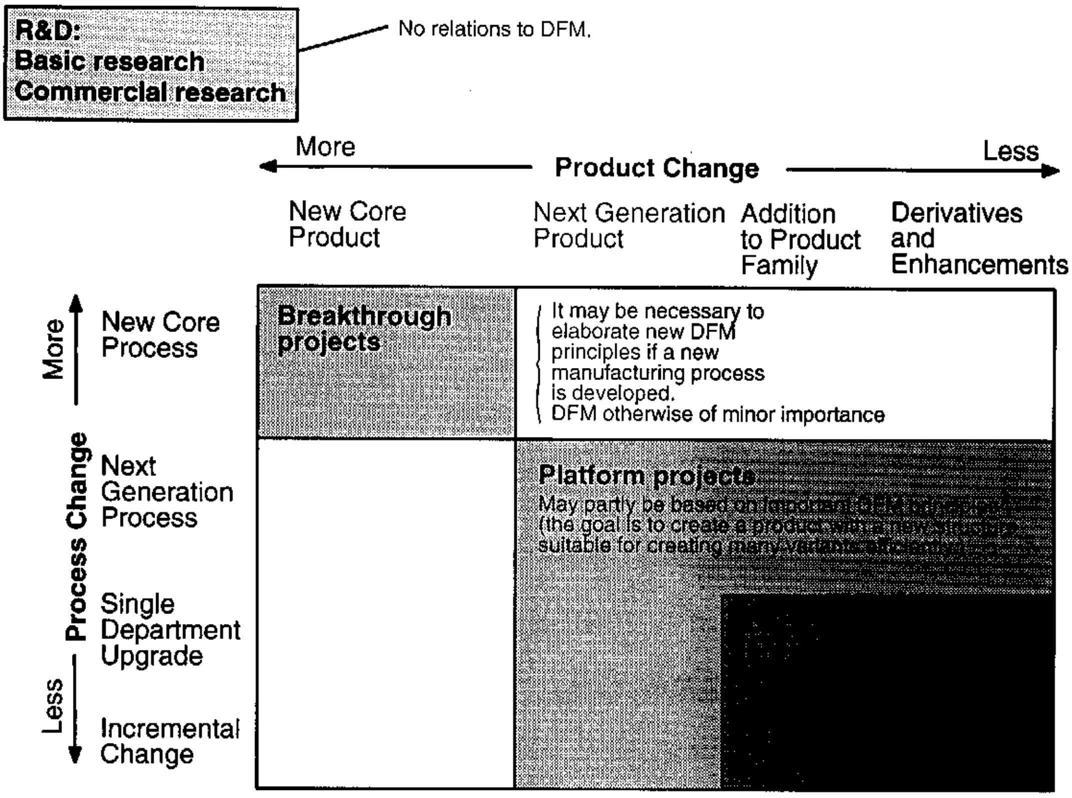


Figure 7. Four types of development projects mapped according to degree of product change and degree of manufacturing process change. Also described are DFM's relations to these kinds of projects. The figure is based on (Wheelwright and Clark, 1992).

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