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MODULE SHEETS FOR ADAPTING MODULAR PRODUCT FAMILIES

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1. Introduction

Today's markets are characterized by the need to rapidly offer customized products at mass production prices. The term mass customization has been coined for the implementation of a hybrid competitive strategy to achieve this goal. Product structuring is among the most successful avenues to effective mass customization. The most commonly used means of product structuring applied today are product platforms and modular product families. The literature on these two concepts is enormous. [Gershenson et al. 2003] identify around 50 different definitions of modularity in academia. [Ishii and Yang 2003] determine similar confusion on the concept of modularity in the industry. It is therefore our view, that the existing contributions to the field of development of product platforms and families are significant. The adaptation of existing product platform and families to new functions and technologies, however, has been largely neglected. Since a platform or family encompasses several life cycles of single products, this topic is of vital importance.

This contribution is structured in the following manner. In Section 2, the work presented here is positioned within research. For that purpose, the business context, triggers, and measures for the adaptation of modular product families are described. It is shown how this contribution relates to these aspects. The primary role of the proposed module sheets should be to ensure that the key properties of a modular product family are maintained throughout all adaptations. That is why we analyze three of the most prominent methods for defining modular product families and determine their primary outputs in Section 3. These primary outputs are the key properties of a modular product family that should be captured on the module sheets. The actual concept of the module sheets and its implementation in three industrial companies is described in Section 4.

2. Positioning within research

In this section, we structure the field of adaptation of modular product families by describing the business context, its triggers, and measures of adapting modular product families. The module sheets are positioned with respect to these aspects.

2.1 Business context

The adaptation of modular product families is to be seen within the business context of variant management and modular innovation.

In variant management, the choice and implementation of products and variants is perceived as the primary determinate of success. Variant management consists of determining a proper tradeoff between the exogenous and endogenous variety. In other words, it is necessary to find the right degree

of variance in the products externally provided to the customer and the resources allocated internally to create these products.
Variant management comprises four strategies that are applied in the different life cycle phases of a product (Figure 1).

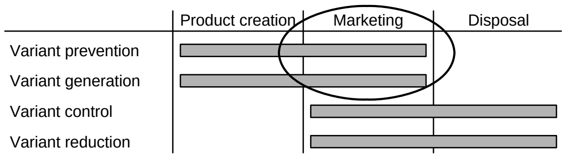

Figure 1. Variant management in the product life cycle

Since the adaptation of existing modular product families is discussed here, the focus is on the marketing phase. In this phase, it is necessary to prevent the development of unnecessary variants through intelligent product structuring, to generate variants where useful, to control the impact of variants through effective processes, and to reduce unnecessary variants.
[Henderson and Clark 1990] distinguish between architectural and modular innovation. In modular innovation, changes are introduced only within the modules of a product. In architectural innovation, the way the modules interact, i.e. the interfaces, are changed. In the adaptation of modular product families, we deal with modular innovation, as one strives to maintain the interfaces until they become outdated and a complete new product structure is required.
In summary, the module sheets introduced in the following are targeted at variant prevention and generation in variant management and to modular innovation. This is because they allow assessing whether a proposed life cycle adaptation satisfies the modules' key properties or not.

2.2 Triggers

The causes for adapting a modular product family can be traced back to a small number of triggers (Table 1). These can be categorized into external triggers from outside the company and internal triggers.

Table 1. Triggers for adaptation

External	*Internal*
Market push	Market penetration
Technology pull	Market enhancement

It can be distinguished between the external triggers of market push and technology pull. In the case of a market push, the customer incites the company to provide a new function. A technology pull represents a new technology encountered by the company that would be beneficial to bring to market. Market penetration refers to the increasing of the market share in a particular segment of the market by introducing new products or improving existing products. Market enhancement refers to the increasing of sales by introducing products to new market segments. All triggers for adaptation are relevant in the scope of the module sheets.

2.3 Measures

A modular product family consists of modules and in some instances also variants of these modules. There are therefore four measures that can potentially be taken in the scope of the adaptation of a modular product family.

- New module
- New variant
- Modification of existing module
- Modification of existing variant

These four measures can be associated to the two internal triggers for adaptation (Figure 2).

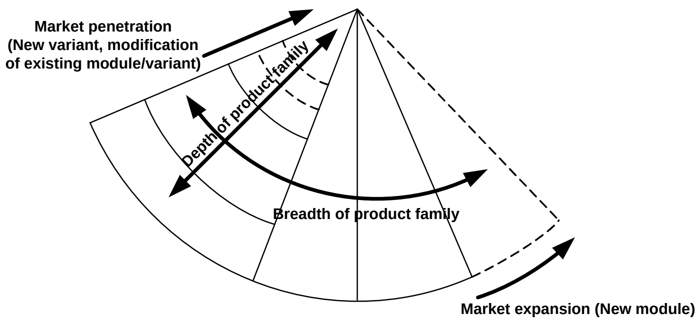

Figure 2. Adaptation measures in relation to internal triggers

A new module allows market expansion as it brings in a new function and expands the potential market. New variants and modifications of variants provide better coverage of a particular function and bring about market penetration. Since we assume that the modification of a module results in a module that is similar in terms of the function, we also place the modification of a module into this category.

The module sheets are associated with all four measures. In developing a new module, one needs to set up a new module sheet with the module's key properties. In developing a new variant or modifying an existing module/variant, it is necessary to maintain the key properties outlined on a previously filled out module sheet.

3. Key properties of a modular product family

Now that the module sheets have been positioned and their role to safeguard a modular product family's key properties has been identified, we look more closely at these key properties. We identify what these key properties are by looking at three of the most common methods for defining modular product families and their outcomes.

3.1 Modularity according to Ulrich

[Ulrich and Tung 1991] provide define a modular product family as having the following two characteristics: (i) "Similarity between the physical and functional architecture of the design" and (ii) "minimization of incidental interactions between components". In deliberately mapping from functions to components, one should thus map every function to one component to obtain a modular product family. Besides, the physical components should be designed in such a way that interaction occurs primarily within modules while minimizing interactions across module boundaries (Figure 3).

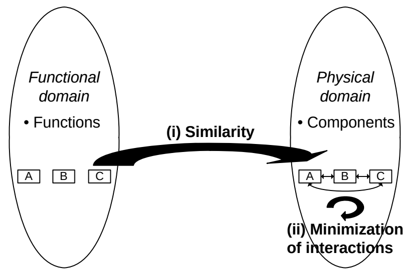

Figure 3. Modularity according to [Ulrich and Tung 1991]

Although [Ulrich and Tung 1991] do not define a method of how to arrive at the definition of a modular product family, they make it very clear that a modular product family consists of two things. First, the modular product family is the product structure, i.e. the structure of the components that the final product is made of. Second, the modular product family is a clear definition of the interfaces among modules so as to reduce interaction.

3.2 Modular function deployment

Modular function deployment (MFD) [Erixon 1998] allows defining modular product families based on the specific needs of the company at hand. In MFD, technical solutions are developed as carriers of the product's functions. The function carriers are then assessed one by one against module drivers. Erixon identifies module drivers from six different areas of interest, namely design and development, variance, manufacturing, quality, purchasing, and after sales (Figure 4).

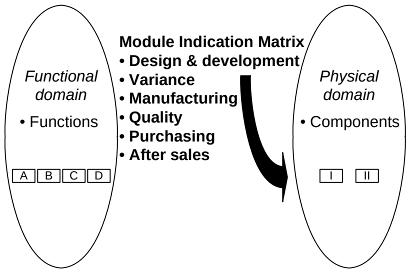

Figure 4. Modular function deployment

Every function carrier is weighted according to its need of becoming a module with respect to each of the module drivers. The resulting numbers are added for every function carrier. The function carriers with the highest sum then become modules. The remaining function carriers are assigned to these modules. Finally, the interfaces among the resulting modules are specified.
[Erixon 1998] specifies a clear process for coming to a modular product family. As in [Ulrich and Tung 1991], the outcome of the process is a product structure and the specification of interfaces.

3.3 Heuristic module identification

[Stone 2000] develops a heuristic method for determining modules in a product. For this purpose, he suggests determining functions as well as energy, material, and signal flows. Functions are described by the operations they perform on the flows. A standardized set of operations (e.g., branch, connect, convert) referred to as functional basis is used for this purpose. The functions are ordered with respect to time and function chains are obtained. The modules are identified by three heuristics (Figure 5). The interfaces among the modules are the flows that cross module boundaries.

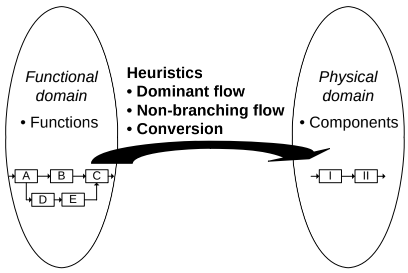

Figure 5. Heuristic module identification

The outcome of the heuristic module identification method is a product structure. The product structure is defined by only looking at flows between the modules, i.e. interfaces.
Based on the analysis of these three prominent methods for defining modular product families, we conclude that the product structure and the interfaces among modules are the most important aspects of a modular product family. Product structure and interface thus are the key properties of a modular product family. The method to safeguard the product structure has already been covered in[Avak 2005]. The safeguarding of interfaces can be carried out using the module sheets as described in the following section.

4. Module sheets

In this section, we describe the concept of the module sheets, the benefits of the module sheets, and how they have been applied in three companies.

4.1 Concept

A module sheet is laid down for every module within a product family. If a module has several variants, there should still be only one module sheet, because the interfaces of the different variants should preferably be very similar. A module sheet consists of three major sections as shown in Figure 6.

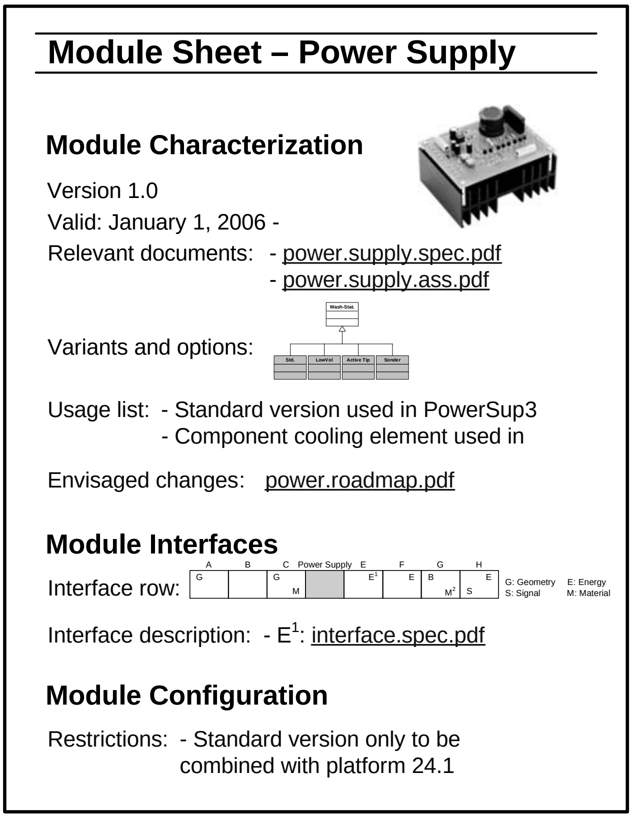

Figure 6. Example of module sheet

4.1.1 Module characterization

The purpose of this section of the module sheet is to give the user a quick overview of the module at hand. It should also guide to additional information on the particular module by providing appropriate links to documents in the corporate document management system. That is why the name, version, and validity of the module are given. Links are provided to more in-depth technical documentation of the module that can generally be found in specifications, detail and assembly drawings, and test reports. Links to business documentation such as sales reports may also be listed. If there are variants of the particular module, these are listed here in a standardized format. A list of end products in which the module is used in is given. This information is essential in order for the user to identify the end products that an adaptation measure will have an effect on. The same applies to envisaged future changes which are to be taken into account as one adapts the modular product family.

4.1.2 Module interfaces

The second section is actually the most important part of the module sheet as it allows capturing the module's interfaces. As described in Section 3, interfaces are one of the two key properties of a modular product family. Generally, these interfaces are only implicitly defined in companies in documents such as detail drawings, specifications, and standards. The problem is therefore not that information on interfaces is not available. The problem is that information on interfaces between modules is hidden and not given explicitly. The second section of the module sheets therefore explicitly captures interfaces and provides an entry point to additional information in the above mentioned documents.

In order to do so, the interfaces of the module with other modules are given using a row from a Design Structure Matrix (DSM) as defined in [Pimmler and Eppinger 1994]. For each interface between two modules, we put in a letter. We distinguish between four types of interfaces: geometry (G), energy (E), signal (S), and material (M). Additional information that might be necessary to understand the role and design of interfaces is given in a list below the interface row. This list also serves as the above-mentioned entry point by giving links to relevant documents.

4.1.3 Module configuration

The knowledge on interfaces alone is insufficient if the user does not know the feasible combinations of modules and variants. Restrictions of compatibility, i.e. configuration rules, are very often applied to relax requirements on interfaces and thus reduce manufacturing costs. That is why it is essential to know the configuration rules of a particular module.

The configuration rules are put down in the last section using simple sentences. In order to facilitate understanding, no standardized mathematical notation as commonly used in configurators is applied here. For very complex products, only the most important configuration rules can be listed here and thus once again serve as entry points. The complete and mathematically stringent listing of configuration rules can also be given elsewhere, e.g. in a configurator.

4.2 Benefits

The primary benefit of the module sheets is the safeguarding of interfaces and thus of one of the two key properties of a modular product family. Additionally, the application of the module sheets entails two less obvious benefits.

4.2.1 Prevention of redesign in other modules

If the module sheets are properly applied, adaptations that are made to one module do not propagate to other modules. This is due to the capturing of interfaces in the module sheet. If the adaptation measure does not alter the interfaces with other modules, then there will be no propagation of change. [Hölttä and Otto 2005] recognized that the interfaces of a modular product have a certain reserve within which changes to the interface do not require changes to other modules (Figure 7).

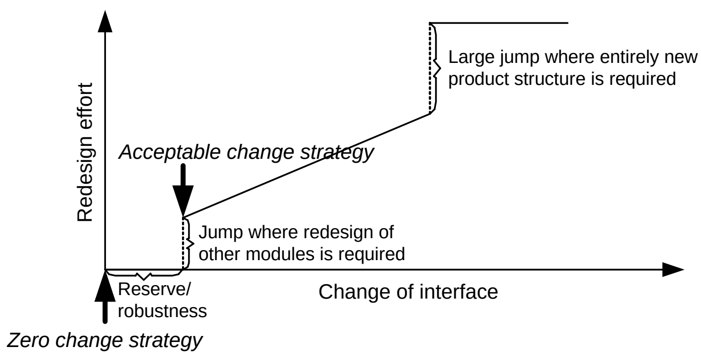

Figure 7. Redesign effort as a function of change of interface

Once this threshold is passed, fixed-step costs occur as redesign effort is required. This effort then increases linearly with the degree of change introduced. Another large jump occurs once the product structure becomes obsolete. Two strategies are therefore feasible in filling out the section on module interfaces in the module sheet:

(i) *Zero change strategy*: No change to interfaces is allowed regardless of whether it causes redesign effort or not.

(ii) *Acceptable change strategy*: Changes to interfaces are allowed as long as they do not result in redesign effort in other modules.

We adhere to the first strategy here. This is because we believe that changes in the interface without changes in other modules will generally reduce the reserve in these interfaces and thereby cause change propagation in the long run. Moreover, using the acceptable change strategy, one would only specify those characteristics of the interfaces that may not change in order to prevent change propagation. These characteristics can, however, change over time and also depend on the second module connected via the interface.

4.2.2 Safeguarding of commonality management

In order to exploit economies of scale, modules are very often reused in parts or as a whole in other products or modules. This is summarized under the term commonality management. Basically, a module can be reused as a whole in another product family or components of the module may be reused in other modules. Commonality management throughout the life cycle of a modular product family can be safeguarded using the module sheets. The end products and other modules that entire modules or module parts are used in are therefore clarified in the usage list in the first section of the module sheet. This allows the user to easily check for commonality management every time an adaptation measure is implemented.

4.3 Implementation

The module sheets have been applied in three companies in the scope of an applied research project.

4.3.1 Rail manufacturer

The manufacturer of rail technology recently launched a new modular product family for rail automation. The module sheets have been applied to capture the interfaces between the main modules within this family and thus safeguard the new product family in the long run. This was carried out in collaboration with the person responsible for the overall concept of this new product family. A mechanical design engineer was consulted for the detailed questions regarding interfaces in the second section of the module sheets. The implementation process took about two working days.

4.3.2 Medical technology manufacturer

The medical technology manufacturer has had its existing product family for several years. In making adaptations to this product family, it frequently occurred that interfaces were not considered. As a result, adaptation measures were either more expensive than initially expected or resulted in costly redesign efforts. That is why the module sheets were used to clarify interfaces. The overall concept of the module sheets was presented to an employee responsible for the system architecture who then implemented the module sheets for all modules within the product family without additional support from our side. In the scope of this implementation, the module sheets were modified and augmented. New types of interfaces were introduced in the interface row while others were left out. Moreover, the module characterization section was augmented with information on the relative economic importance of the module.

4.3.3 Semiconductor equipment manufacturer

The semiconductor equipment manufacturer is in the process of launching a new product family. Just like in the case of the rail manufacturer, the module sheets are used to capture the interfaces between the main modules. So far, this has been done for about a third of the modules. While the initial module sheets were filled out in collaboration between industry and academia, the remaining module sheets are filled out independently with no further support from academia.

5. Conclusion

In this contribution, we have positioned the module sheets with respect to the business context, triggers, and measures of adapting modular product families. Product structure and interfaces have been identified as the core properties of a modular product family. These are to be safeguarded in adapting a modular product family. Module sheets have been proposed for this purpose. The module sheets consist of three sections in which interfaces, configuration rules, and the module itself are characterized. The context in which the module sheets have been applied in three industrial companies has been described.

After some initial effort from our side, the module sheets were willingly applied at our industrial partners. We believe that this is due to two reasons. First, interface management is an important topic in companies today, particularly since the advent of product families and platforms. Second, the module sheets are rather simple to understand and apply. In applying the module sheets, it is, however, important not to regard them as a rigid concept. Instead, one should rather adapt the module sheets to the needs of the company at hand. That is why one should add additional information within the module sheet's three sections where necessary and also eliminate dispensable information in the particular corporate context.

Acknowledgement

This paper is dedicated in memoriam of Prof. Dr. Markus Meier. Markus Meier was Professor of Mechanical Engineering, head of the Center for Product Design and a member of the Department of Mechanical and Process Engineering at the Swiss Federal Institute of Technology Zurich from 1996 to 2005.

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