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Harmonizing cross-departmental Perspectives on Modular Product Families

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Abstract

In order to maintain their competitiveness and to respond effectively to different customer needs, manufacturing companies offer a wide range of product variants. This increasing product variety leads to an increase in variety-induced complexity and thus to rising costs in all departments. The development of modular product families is a proven strategy to handle the large external variety with a relatively small internal variety. Modularization requires not only technical-functional, but also organizational, process-related and strategic aspects from all involved departments in order to create an optimal product architecture. The method of the Life Phases Modularization offers this possibility as it integrates all perspectives of the different departments and tries to harmonize the partially contradictory aspects using the Module Process Chart (MPC). The resulting harmonized module process forms the global optimum for exploiting potentials of modular product families within the entire company. The method was developed almost a decade ago and has been applied and refined over time in several industrial cases. This paper presents the method on the basis of two industrial examples and shows deficits and improvements in a consolidated manner.

Keywords: Modularization, Product Family Design, Harmonization, Prespectives, Case study

1. Introduction

In order to meet different customer needs, manufacturing companies offer a wide range of product variants to ensure their competitiveness. However, as the number of variants rises, the internal variety of components and processes increases, which in turn leads to increased variety-induced complexity [1]. The result is a challenging development task with many dependencies on all areas of the company. For example, the design department needs to do additional work to create the variants; procurement has higher purchase prices due to lower unit quantities; production has complicated production control; quotation costing in sales is more complex and service has to provide more spare parts. This all leads to a loss of transparency and ultimately to higher costs throughout the company [2].

Systematic product structuring can help to develop product families that cover a wide variety of customer requirements, while at the same time managing with as little internal variety as possible. In this area, modular product family design has firmly established itself as a product-related approach to variant management [3]. When developing modular product architectures, the perspectives of all departments, such as sales, purchasing or production, must be involved in the development process, since most of the advantages of a modular designed product family lie in the processes of these departments (simpler product configuration, etc.) and not necessarily in the product itself [2, 4].

One approach that combines this product-strategic perspective with the technical-functional view is the Life Phases Modularization according to [5]. This method was already developed several years ago and has been applied multiple times in an industrial context. Due to the several applications, improvement potentials could be identified, which shall be presented in this paper in combination with possible solutions. For this purpose, the initial method is first introduced and illustrated by two industrial case studies using a vacuum cleaning robot and pressure regulating valve family. The empirically identified potentials for improvement are then shown and the solutions developed are proposed. Finally, an outlook on the further use of the approach is given.

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2. Perspectives on Modularization

Regarding the modularity of products, various definitions and views exist in the literature [2]. Since the modularization of products has effects and potentials for all product life phases, many approaches have been developed, which, however, pursue very different goals. In [6], a comprehensive overview of the different views and approaches is given. A differentiation can basically be made between the technical-functional, process-related and organizational as well as product-strategic perspective.

In the technical-functional view, the product is modularized according to aspects of technical functionality or according to functions and their properties, e.g. when using design structure matrices (DSM) [7]. The organizational and process view aligns the modular design with the organizational structure of the company or the resources of the processes in the product life phases. From a product-strategic perspective, the medium and long-term strategies of the company and the individual product life phases are supported by means of targeted modularization. Here the concept of life phases is utilized to make the best possible use of the various advantages of the departments [8]. Especially the product-strategic view shows that the consideration of modularity should not be limited to a single product, but offers the greatest leverage especially when considering product families with many variants [6].

The different perspectives are not independent of each other, but influence themselves mutually and pursue different focal points of the topic [2]. For this reason, when a modular product family is planned, all perspectives should always be taken into account and the departments involved in the product development should be integrated.

3. The Module Process Chart (MPC)

As a method unit of the Integrated PKT-approach for the development of modular product families, the Life Phases Modularization aims to include these requirements and goals of all departments in the modularization [5]. The MPC provides support in identifying conflicts and contradictions between the individual life phases. The tool was first presented by [5] in 2010 and has since been used in more than thirty industrial and student projects. During this time the method was continuously developed further. The MPC serves the representation of the module process along the company processes. For this purpose, the life phases are related to the components of the product family. Fig. 1 shows the schematic representation of the MPC using the example of a product family with four components (A-D) and life phases (development, production, sales, use).

The components are coded according to their use within the product family (optional, variant, etc.). Through grouping and color differentiation, the respective modules are visualized for each phase of life. Between the life phases, the components are connected with each other by lines so that the flow of this component or module can be traced along the value creation process. A special feature of the tool is that the "end product" is depicted as an additional life phase - here the product variants

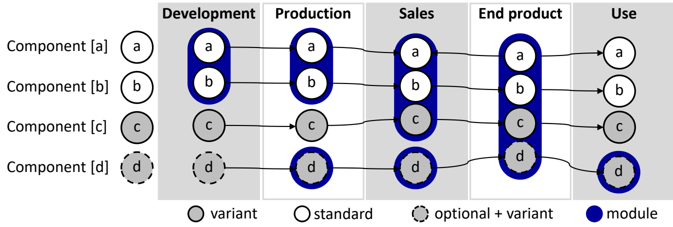

Fig. 1. Schematic representation of the MPC based on [5]

of the product family are available in physical form as a complete product before it passes into the usage phase. The selection and sequence of the life phases is not fixed and can differ depending on the application case.

3.1. Essential concept of the MPC

The tool is based on the principle that there is not only one modular product structure with which all company divisions work, but that each phase of life strives for its own modularization. This is useful because there may be different reasons for module formation for each department. A comprehensive overview of the effects of modular product structures is given by [9] using a literature-based impact model. Production, for example, has great advantages if it can form pre-assembly modules in order to achieve the fastest possible process without problems and shorter lead times [10]. Development, on the other hand, usually has a functional perspective on the product and wants to cluster it in such a way that the functions make it possible to form development teams (e.g. mechanics, electrical engineering) and, thus, to work simultaneously [4]. The MPC makes it possible to consolidate these different "desired modularizations" in one representation and to harmonize them in the next step, so that the individual life phase specific module structures are coordinated with each other. From a cross-departmental perspective, this provides the greatest possible benefit for the entire company [5].

3.2. Methodical procedure for creating and using the MPC

It is a special feature of the MPC that not only a technical-functional or product-strategic perspective is pursued during module formation, as with existing methods, but both aspects are combined with each other [2]. The basic procedure for creating and using the MPC consists of four steps, which are briefly described below.

Technical-functional modularization: As a starting point for the method, a technical-functional module structure based on the components of the product families will be developed. Using the adapted method of module heuristics according to [11], not just the interactions between functions are analyzed and used for module design, but also the flows between the components. This can be, for example, an electrical flow, a flow of a liquid or also a structural force flow between the components. The technical-functional driven modular design from the perspective of development serves as the basis for the following product-strategic modularization.

Product-strategic modularization: In order to integrate the requirements of all departments, a separate modularization for all life phases is developed in addition to the technical-functional one. For these modularization concepts, the module drivers of all phases of life are considered according to Modular Function Deployment [8] and compiled on the basis of a generic list (Tab. 1).

Tab. 1. Module drivers according to [5] and [8]

Development	
Technical-functional module driver	Technical-functional requirements for the product structure are generated by a technical-functional approach (DSM, heuristics according to Stone).
Temporal variety	Design or technical specifications of the module are subject to planned modifications or will be replaced in the course of a technology change.
Carry-over parts	The module shall be carried over from a previous product generation or be carried over in the next product generation or is shared with other product families.
Purchase	
Modular sourcing	The module shall be bought-in, because of economical, technical or strategic reasons.
Production	
Process	The module is subject to special production or assembly processes.
Organization	The module is suitable volume of work for an organizational unit.
Separate testing	The module shall be tested separately before the final assembly.
Sales	
Variant product properties	The module includes a differentiating property of the product family.
Use	
Adaptation/extension	The module needs to be changeable for adaptation or extension of the product.
Service/maintenance	The module needs to be demountable for maintenance and inspections.
Recycling/Disposal	
Product recycling	The module shall be carried over in a new after-sales phase while maintaining its properties.
Material recycling	The module shall be used for a new production process.
Thermal recycling	The module shall be thermally recycled.
Disposal	The module shall be disposed of.

In addition to the module drivers, the case-dependent specifications of the module drivers must be defined for the unambiguous assignment of components to modules [5]. In order to be able to carry out module grouping, the components are assigned to the respective module driver specifications in the various life phases using the modified modularization network planning technique (Fig. 2). The result of the product strategic modularization is a network plan for each life phase with the documented module decisions.

Harmonization of different perspectives: In order to derive a continuous process from the product structures of the various phases, they must be coordinated with one another, whereby contradictions between the individual views of the life phases are identified and resolved.

For this purpose, the specific modularizations per life phase are compared with each other using the MPC, before contradictions in the individual modularizations of the life phases are identified and approaches to solutions are pointed out. One premise for the creation of the module process is that the modules should ideally become larger and larger up to the end product [5]. Splitting a module into individual components again in a subsequent life phase can lead to problems in the interfaces between the departments and cause unnecessary processes. As part of the harmonization process, compromises are sought in consultation with all departments and possible solutions discussed until a consistent modularization concept is developed. Not all life phases have to work with the same modularization; they just have to be compatible with each other.

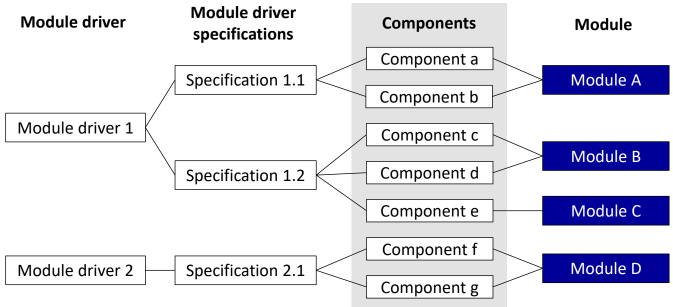

Fig. 2. Schematic network plan for product-strategic module grouping according to [5]

Definition of the final module process: Finally, the specified modular product structure is defined and documented company-wide so that a constructive implementation of the modules can follow. Special attention should be paid to the definition and the simplest possible design of the module interfaces in order to facilitate the interchangeability of modules constructively. It is also important to consider the requirements for module design from the various product life phases during implementation.

4. Applications and improvements of the MPC

Based on a multitude of experiences, the MPC is very versatile and suitable for industry-independent applications. The method has already been used in various industries, such as mechanical and plant engineering, aviation, metrology and medical technology, as well as in small companies and multinational corporations. The presentation of two application cases (vacuum cleaning robots and pressure regulating valves) is intended to clarify how the method works, which of the method steps are to be applied on a case-by-case basis and which differences may result from this. In addition, deficits and improvements of the tool are derived from empirical studies.

4.1. Case 1: Product family of vacuum cleaning robots

In order to obtain a suitable level of abstraction for the tasks of modularization, the internal variety of the product family is first analyzed and transformed into a generally comprehensible and thus interdisciplinary communicable representation. For this purpose, the Module Interface Graph (MIG) has been established [12], which represents not only the variety but also the rough form of the components of a product family as well as their flows and interfaces (Fig. 3, left).

Fig. 3. Representation of the vacuum cleaning robot family using a MIG [12]

With the help of the MIG and the heuristics according to [11], the modules are initially formed from a technical-functional point of view. The results of this modularization are incorporated into the second step of product-strategic modularization, where they are used in the life phase of development as drivers for modularization using the introduced network plan technique.

For the life phase of production, module formation using this technique is exemplarily illustrated in Fig. 4. The module driver *organization* has been assigned the case-specific characteristics of the various pre-assemblies (*bin*, *left* and *right wheel*). This brings the greatest advantages to production, as they think in terms of assembly units and such a division enables parallel pre-assembly and shortens throughput times. The *separate testing* of electronic components can also reduce costs, since not every module would have to undergo such a test. Components may be related to several module driver variants (e.g. *rotor motor* to *preassembly bin* and *electrical test*). Here the module allocation has to be decided in the individual case and the decision has to be documented. In this case, production has more advantages in pre-assembling the component and not being able to test it separately.

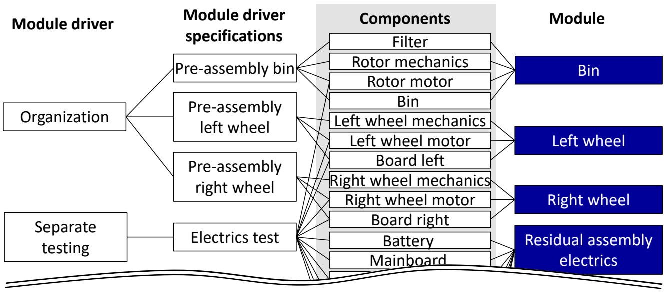

Fig. 4. Excerpt from the network plan of the production phase

According to this scheme, the modules from the other life phases are also formed and combined in the MPC (Fig 5, above). With the help of this initial MPC, critical points in the module flow can be visually identified. In the case of the *filter* (point of conflict 1), the sales department would like to handle this component separately as a variant module in order to be able to respond as quickly and easily as possible to the required customer needs (e.g. in the form of an internal sales configurator). For maintenance reasons, it also makes sense to treat the filter separately as an easily replaceable module during the usage phase. In the preliminary phases, however, the filter is developed, purchased and assembled together with other components in a common module. This severely hampers adaptation to customer requirements and maintainability. For this reason, during the harmonization process, it has been decided to resolve the conflict in favor of sales as well as use and to treat the filter as a single module throughout the product life cycle (see harmonized MPC in Fig. 5, below). Although this requires an adaptation of the upstream processes, it brings the greatest possible benefits for the company as a whole.

Further points of conflict (2-4) can be found in procurement. In this phase of life, the modules are formed by trying to obtain good conditions from suppliers through the highest possible

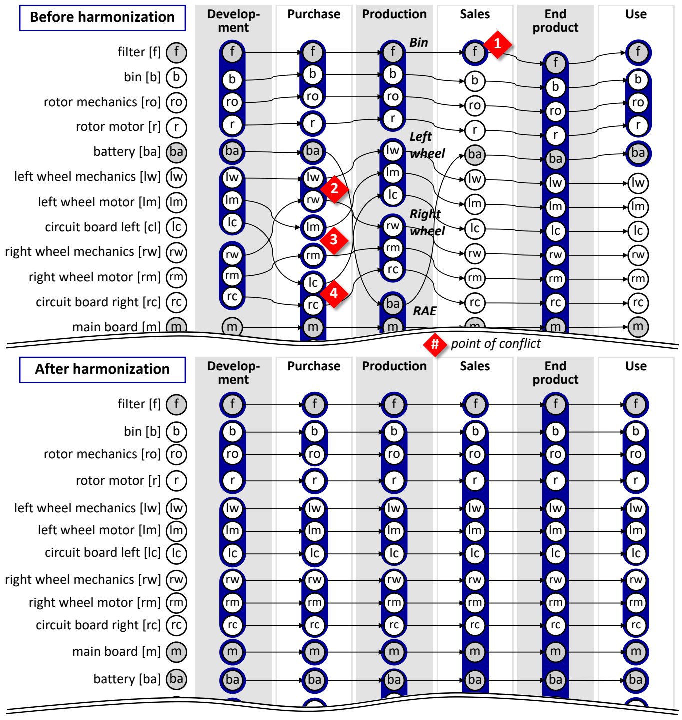

Fig. 5. MPC before and after the harmonization of the module process for the product family of vacuum cleaning robots

number of similar components. In this case, however, this impedes the module flow between development and production, which both have an identical module concept. Since in this case a relatively high proportion of the value added is generated in these two phases, procurement must make a compromise and adopt the module structure (Fig 6, below). This ensures that the flow is guaranteed without separation of modules and that, for example, standardized documentation can be used right through to the end product. The purchased modules can be delivered more easily to the respective assembly stations, which reduces errors and thus shortens lead times. If the conditions from procurement had predominated, the module structure could also have been adapted to the other two phases. It is usually a compromise whose argumentation can be made more transparent by the MPC and discussed together with all departments.

4.2. Case 2: Product family of pressure regulating valves

Analogous to the first case, the MIG is created for the pressure regulating valves, in which the components of the product family are mapped (Fig. 6).

The manufacturer of the pressure regulating valves pursues a different corporate strategy than the manufacturer of the vacuum cleaning robots: individual solutions are offered to the customers, which are usually developed on the basis of existing products (engineering-to-order). Compared to the previous example, this results in a different sequence of the life phases (sales at the beginning) and an additional phase of assembly, which is downstream of the actual manufacturing.

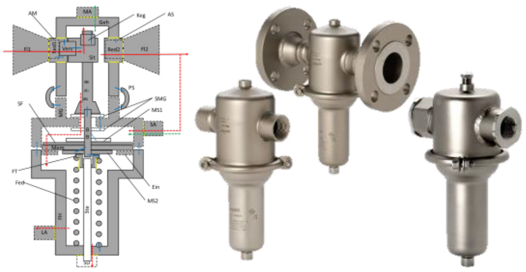

Fig. 6. Representation of the pressure regulating valve family using a MIG

The network plans are created again for the defined life phases. Fig. 7 shows an example of the network plan for the development phase. The module driver *carry-over parts* has two specifications in this application example: *standard parts* and *in-house-production*. Standard parts contain the standardized purchased parts to be adopted, while in-house production is linked to internal standard parts. From the valve manufacturer's point of view, it is important to consider the various carry-over components, since the aim is to configure the various product variants from as many existing components as possible. The modules from the perspective of development result from taking this product-strategic consideration and the technical-functional perspective into account.

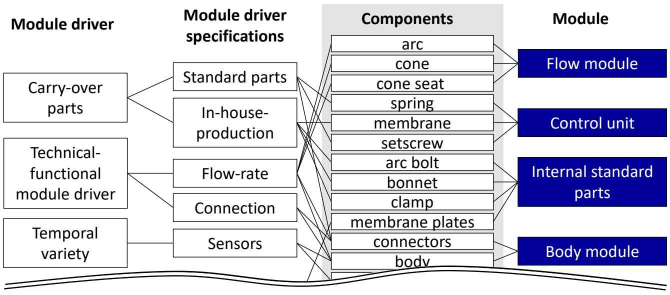

Fig. 7. Excerpt from the network diagram of the development phase

The initial MPC is assembled again from the various modularizations of the individual life phases and the points at which the module process is not yet optimally harmonized are identified (Fig. 8, above). The *body module* (development) faces the problem that the components *body* and *connectors* are separated in purchase (background are different suppliers for the two components) and then merged again in manufacturing (point of conflict 1). There, both components are regarded as one module because they are dependent on each other in terms of the manufacturing process (e.g. with regard to permitted tolerances and material qualities). For this conflicting point, a compromise is necessary, since in an optimal module process the modules should become larger and larger [5]. In the present case, the arguments of the purchasing department are decisive for the harmonization, since the two components are long-running and separate procurement results in greater flexibility in purchasing and thus shorter delivery times. Development splits up the module accordingly and delivers it separately to purchase (see fig. 8, below).

Further points of conflict (2 and 3) refer to the module allocation of the *cone* in the transition from development

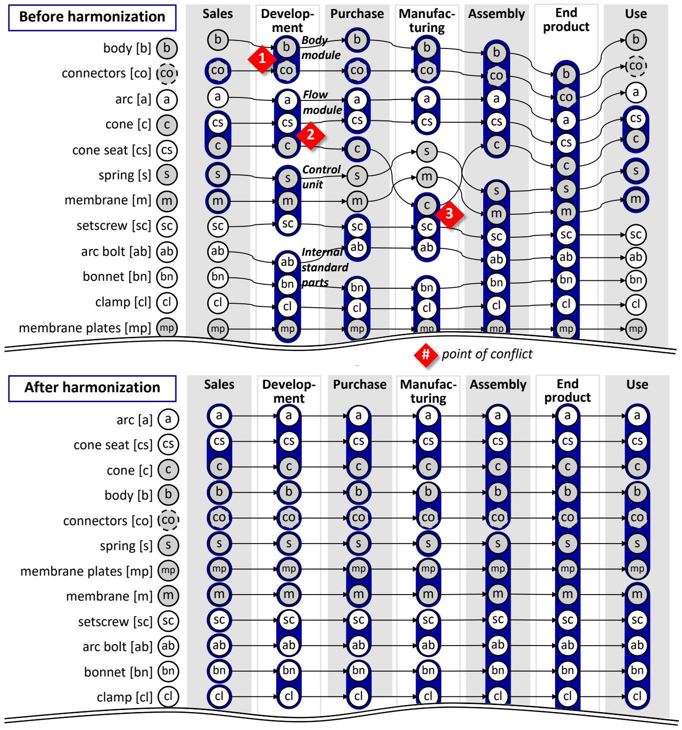

Fig. 8. MPC before and after the harmonization of the module process for the product family of pressure regulating valves

(technical-functional view), purchasing (supplier view) and manufacturing (process view). The module formed in development represents a functional unit and realizes one of the core functions of the product with the flow control. The three components contained (including the cone) must be carefully adjusted to ensure correct control of the fluid. In order to ensure this function and still guarantee an optimally coordinated module workflow through the company, the *flow module* from the development is adopted for the following life phases during the harmonization process (Fig. 8, below). In this case, manufacturing has to make the compromise and adapt the production process with the new module. The functional orientation, however, minimizes errors and thus saves time and effort for their elimination (which usually occur in production).

The harmonized module structure in the MPC is more fragmented (many small modules), especially in the first three life phases than it was initially developed in the network plans. However, it offers greater overall flexibility to respond to customer requests, technological developments or changes in the supplier structure.

4.3. Deficits and improvements

In addition to the two examples presented, the MPC was also used in 13 other companies and in 32 training projects. In the following, the deficits identified and the improvements made are summarized in condensed form.

One of the main deficits in the harmonization process is the *lack of criteria for evaluating the optimal module process*. Here only the minimization of branching is given as an aid and that the modules should become larger and larger as they progress. However, specific economic parameters for the individual departments are often also of importance and must be taken into account when deciding on harmonization. In production, for instance, these include reduced throughput times, which can be regarded as key drivers for modularization in general. These department-specific key performance indicators are developed on a case-by-case basis and used as optimization criteria in the improved MPC procedure.

Furthermore, *additional information on the components* is relevant to support the decision for or against module formation during the harmonization process. Since modularization is applied here for variety management reasons, the degree of variance of a component is of great importance. In the original MPC, this information was previously only stored in binary (variant or standard) and visual form (grey or white). This deficit was adjusted in the revised MPC and solved in such a way that the number of variant components as well as the number of modules for the respective life phases are represented. Minimizing the number of variant modules can also be seen as a further goal during the harmonization. In addition to the variety, further information on the components can also support the module decisions. In previous use cases, these included e.g. material costs, schedule criticality or probability of changes over time. These are stored in the MPC with newly introduced symbols.

Another shortcoming of the method is that *no alternative harmonizations are created*, but only a single solution is worked out. Thus, while comparisons can be made with the reference situation prior to modularization, it is not possible to be sure whether there is a better solution (also with regard to the newly introduced department-specific indicators). For this reason, at least three alternative harmonized concepts are always developed in the adapted procedure, allowing a relative comparison to be made.

In the context of the *multi-criteria optimization problem* the question of a software support or an algorithm for the solution arises. Within the scope of a pilot study, a developed MPC software was applied, which, however, was used by the participants less for optimization than for generating the MPC alternatives. The background here is that, in addition to calculable parameters (such as throughput time), strategic parameters are also relevant in harmonization. These cannot (yet) be quantified and accordingly cannot be optimized. People still have to make the decision here. For this reason, the inclusion of cross-departmental decision-makers (e.g. general managers) at this point makes more sense than basing the decision for or against an alternative solely on the results of an algorithm. Nevertheless, the software has supported the implementation of the method and is still used.

5. Conclusion and Outlook

The MPC considers and integrates technical-functional, organizational, process-related and also strategic aspects from all departments involved in the product life cycle and tries to balance the disadvantages of other integrative methods in practical application. Under these partially contradictory boundary conditions, modularization is not an optimization task, but involves all aspects of all phases of life, leading to a harmonized modular product structure [2]. This harmonization is supported by the MPC, which was first illustrated schematically and then by means of two examples in this paper. Based on many years of experience from industrial and teaching projects, the deficits of the method were collected and improvements were incorporated. These enhancements were finally presented in a consolidated manner.

The MPC can be furthermore extended to include a service view in order to map the module structure of product-service systems and to enable a cross-departmental view of the interaction of product and service.

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