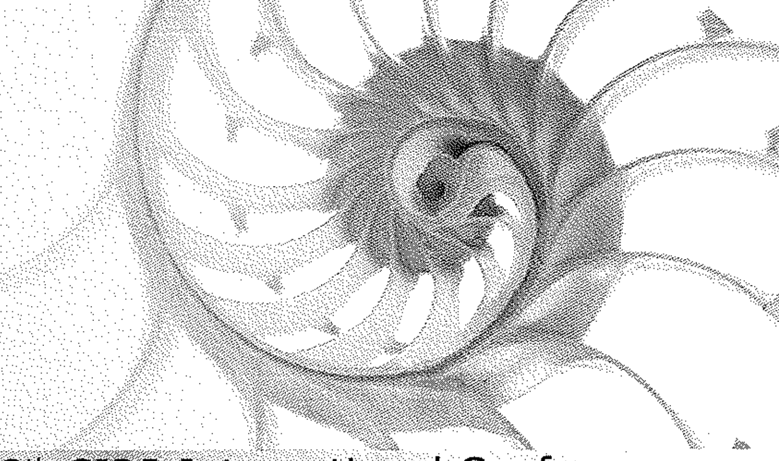

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# Product Structuring - the Core Discipline of Product Lifecycle Management

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**Abstract**

The product structure plays a major role in product lifecycle management. It defines the structured relationship among product items and integrates all product related information. To effectively support lifecycle management implementation, initiatives to define product structuring reference models must consider that the process that best fits a specific project may vary according to the development context. Therefore, based on a project typology in mechanical engineering, this article presents a set of six customized product structuring reference models to address the specific needs of each existing project type. The benefits for the industry include better process suitability and reduced implementation cycles.

**Keywords**

Product Structure, Product Lifecycle Management, Reference Model

## 1 THE CENTRAL MEANING OF THE PRODUCT STRUCTURE FOR THE PLM

Increased product diversity, higher technological complexity and faster innovation cycles are some of the most significant trends currently impacting industrial enterprises. The combined influence of these factors leads to an explosion on the amount of product related information.

In order to efficiently manage all product data, guarantee process transparency over the extended supply chain and support a paradigm change from functional focus to the management of complete product lifecycles, many companies are implementing product lifecycle management (PLM) initiatives.

PLM is a systematic concept to manage and control all the information needed to document the product through its entire lifecycle, from the initial idea to end-of-life [1]. PLM is therefore not only an IT system, but moreover a comprehensive management and integration approach for processes, software tools (applications and data) and the organisational structure [2]. Goal of this integration is to overcome the existing organisational barriers and to streamline the value creation chain [3].

In this context, the product structure plays a fundamental role for the PLM implementation. The product structure defines the physically structured relationship among the modules and components which constitute a product and integrates all the product related information and documents (e.g. CAD models, NC programs, cost analysis, maintenance procedures, disassembly plans) [3]. The product architecture links therefore all objects which represent the lifecycle information of a product. An object is in this sense a generic concept for multiple elements within the product structure, including product requirements, functions, single components, assemblies or the product itself [4]. The role of the product structure within the PLM is then to manage all product related objects and their structural connections [5].

The central meaning of the product structure to the PLM indicates that companies can benefit from a reference model which encompasses the successful practices related to the product structuring process. However, recent research results as well as evidence from the practice collected at numerous projects conducted by the WZL indicate that the product structuring cannot be defined as a unique reference model for all companies and all their development projects. Moreover, even in a single industry sector, the process that best fits a specific company may vary according to multiple characteristics of the development projects like the innovation level and the number of product derivates.

Based on this fact, this article presents a set of six different product structuring reference models customized according to typical project characteristics defined by an existing typology for development projects at the mechanical industry.

After an introduction on the importance of the product structure for the PLM, the product structuring activities are described and formalised in a lifecycle oriented process for further deployment. The development project typology and the existing development project types are than presented. Based on the typical project types, customized product structuring reference models are derived from the theory and practice and described in detail. Finally, examples at the industry level provide an insight on how the typology and the resulted product structuring reference models can be applied in practice and demonstrate the existing benefits.

## 2 LIFECYCLE ORIENTED PRODUCT STRUCTURING REFERENCE PROCESS

A lifecycle oriented view of the product structuring process considered in this article consists of five steps which, based on the product requirements, result in the design of product modules and the corresponding interfaces with the highest possible degree of commonality in the product program. By going through the individual steps, combination rules which link the elements of the product structure are defined, building the entire modular structure and the configuration logic. The configuration logic is not only implemented on the component level, but also built up on the requirement and functional level [4]. Configuration management means in the context of this paper the logic how a product is build up from modules and components. Figure 1 illustrates the five steps process schematically.

The starting point for the product structuring is the identification of the requirements of every stakeholder along the entire product lifecycle. Both the direct customer and the internal requirements from the technology, the assembly and the after-sales departments among others must be considered. Special attention must be given to disassembly and recycling requirements and regulations to assure that these aspects are since the beginning considered in the product structure [6]. All requirements have to be checked with the overall product strategy. The most relevant requirements for the product differentiation to competitive products should also be clearly identified. Considering the existing combination restrictions and conflicts, the defined requirement profile is linked to the related product functions and specifications (1).

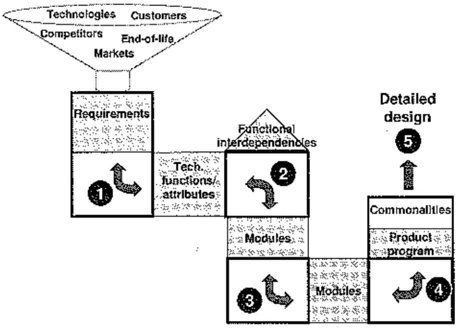


Figure 1: Lifecycle oriented product structuring [4].

In a next step the identified product functions are transferred into the corresponding physical modules considering the available technologies and the function-related costs / prices (2). In this context, a module represents an element of the product structure which provides one or more product functions independently and which is associated to other modules through interfaces. In order to guarantee variant differentiation for the end user, the differentiation criteria identified at the beginning of the process should not be combined together at the same product modules.

The interfaces between the modules are defined in step three based on the functional interdependency between the modules (3). The creation of standardized interfaces allows a versatile combination of modules and supports therefore an efficient generation of product variants. On the other hand standardised interfaces are more expensive than an integral design or a direct interface. The decision for or against a standardised interface has to consider the costs for the interface.

The defined product structure (modules and interfaces) has than to be analysed regarding the commonality (4). Commonality in this context can not only be realised on the different levels of the product structure, but similar technologies, production processes and organizational structures also provide inputs for the identification of potential commonalities. The corresponding configuration logic including possible combination restrictions and mandatory choices is than defined to support the sales department. Finally at the last step the product structure must be completely detailed to component level and all product related information has to be linked to the product structure (5).

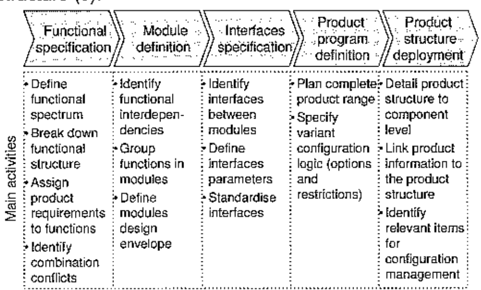


Figure 2: Product structuring process.

The five steps lifecycle oriented product structuring process described above is presented in a process phase notation in Figure 2. This picture summarises the most important activities in each process step and serves as a basis for the further process customisation according to specific development project characteristics.

The presented lifecycle oriented approach to product structuring considers the complete product derivates that might be further developed already in the early stages of the process. This approach supports simultaneously a high differentiation degree to fulfil customer individual requirements while at the same time avoiding unnecessary variants and maximizing the commonality degree, providing the required solid fundament for an efficient PLM implementation [4].

## 3 TYPOLOGY OF DEVELOPMENT PROJECTS IN MECHANICAL ENGINEERING

Product development activities are company specific and have to be aligned to the individual context and boundary conditions of the each project. An adequate project typology can support the identification of relevant project characteristics even before project initiation and guide the configuration of forthcoming development projects activities in consideration of all relevant factors, allowing a faster project initiation.

In this research we consider an already existent development project typology developed for mechanical engineering industry [7]. This typology is based on four main criteria: innovation level, technological novelty level, order type and assortment strategy. The innovation level refers to the innovation degree impacting components and the whole product architecture [8]. The technological novelty level describes the newness perceived by the company [9]. The order type defines kind and scope of customer integration into product development. Finally, the assortment strategy is defined by the number of variants and the point in time for variant development, introduction and fade-out. Figure 3 presents a morphological box which summarises the typology criteria and their possible attributes. For a detailed discussion about the model criteria and their attributes refer to [7].

| Typology criteria | Criteria attributes | | | | |
|---|---|---|---|---|---|
| Innovation level | Incremental innovation | Modular innovation | Architectural innovation | Radical innovation | |
| Technological novelty level | Low technology | Multi technology | Interdependent technology | High technology | |
| Order type | Generic development | Target group oriented | Early customer integration | Engineer-to-order | |
| Assortment strategy | 100% Engineering | Job # 1 Engineering | Release Engineering | Add-on Engineering | Non-variant Engineering |

Figure 3: Typology model for development projects [7].

Project types can theoretically be defined as a combination of criteria specifications in all dimensions of the typology model. Based on these criteria, six typical development projects types in the mechanical engineering industry have been identified: step-by-step development, release-oriented development, add-on development, probe-and-learn development, lead-user development and tailor-made development. The project types and their attributes for each criterion are presented in Figure 4.

Step-by-step-development projects are characterized by incremental innovations, by the use of low technology, by target group oriented development as well as by 100%

engineering (Figure 4). The development always starts with existing products which are improved on a small scale only, i.e. the performance of a single, existing product function is modified (incremental innovation). According to this, only a few new technologies showing no significant interaction with each other are used (low technology). An example of such a development process is the enhancements of a wind energy plant family. For this development project, some of the existing components only had to be removed to the redesigned gondola.

Release-oriented development is applied primarily to highly complex products. In order to control the complexity the product is unitized consequentially into release units. Through clearly defined interfaces the release units can be developed - as modular innovations - independently of each other and of the entire product. The cockpit of a car and the spindle of a machine tool are examples of a release unit.

| Criteria / Types | Innovation level | Technological novelty level | Order type | Assortment strategy |
|---|---|---|---|---|
| Step-by-step | Incremented innovation | Low technology | Target group oriented | 100% Engineering |
| Release oriented | Modular innovation | Multi technology | Target group oriented | Release Engineering |
| Add-on | Architectural innovation | Interdependent technology | Generic development | Add-on Engineering |
| Probe-and-learn | Architectural innovation | High technology | Target group oriented | Job #1 Engineering |
| Lead-user | Radical innovation | High technology | Early customer integration | Job #1 Engineering |
| Tailor-made | Architectural innovation | Interdependent technology | Engineer-to-order | Non-variant Engineering |

Figure 4: Development project types.

In contrast to the two types mentioned above, add-on development projects lead to "new" products. In this context "new" means unknown to the customer or not expected by him. Add-on developments are based on existing products as well, but they modify their functionality and/or add new functions in such a manner, that the customer recognizes the product as new. An example is the development of the so-called "no-frost-technology" for fridge freezers for which certain additional air channels, fans and evaporator concepts were integrated into an existing product.

Basically, probe-and-learn developments are characterized by the fact that they partially lead to totally new ways of employing and using a product thus addressing market segments a company has not yet occupied with its product range. As an example there is the development of a new generation of commuter trains, now made of modules, or the development of a new product line, e.g. the Porsche Cayenne.

Projects of the lead-user development type aim for the development of a product or a product family that is a complete novelty in the market and differs from the existing products of a company in such a manner that a new business area must be conquered. An example for this project type is the build-up of the business area assembly technology by a professional tools producer, for which fifteen selected lead-users helped to develop a totally novel assembly technology.

Finally, the developments ordered by a customer, leading to a highly specific product for which the customer acquires the exclusive and -if necessary- time-limited rights to use, are called tailor-made-developments. An example of this project type is the development of a production line for daily contact lenses ordered by a single customer.

## 4 PRODUCT STRUCTURING SET OF REFERENCE MODELS

Based on the characteristics of the project types defined by the typology described previously, the basic product structuring reference model presented on Section 2 has been deployed in a set of six reference models specially customized to fulfil the specific needs of each different project type. The project types and the approach of product structuring has been shown in several projects in industry. Examples for the approach are given in sector 5.

Each one of the six customized reference models is presented in a picture similar to Figure 5. The five process phases represented at the top of the picture remain unchanged for all customized processes. The "existing product" description on the top left hand corner identifies the specific project types in which a previous similar product already exists and can be used as a source of information. The main product structuring activities are listed in the middle of the picture. The effort distribution along the process is then decribe just below the activities. A full black ball indicates the most important phases in which effort should be concentrated, while a full white ball represents a less significant phase for the specific process type. Finally, the process focus for the specific process type is summarised.

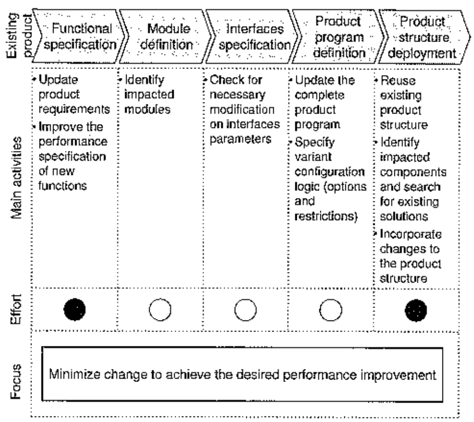


Figure 5: Reference model for step-by-step development.

Figure 5 illustrates the product structuring reference model for step-by-step development projects. This type of project is characterised by incremental enhancements in an already existing product. In this case, the process focus is to minimize change to achieve the desired functional performance improvement. The product structuring begins with gathering and updating the product requirements. The performance parameters of existing functions are then adjusted to meet the needs of the updated requirements profile. If necessary new secondary functions can also be specified. Secondary functions are either supporting functions or functions only for some products. The second process step comprehends the identification of the modules impacted by the enhancement on the functional specification. Ideally modules interfaces should not change to avoid part proliferation and lack of standardisation with other existing product families. Based on the new product specification, the complete product program including all variantes has to be updated. Considering that the new product is a follower of a previous generation, the detailed definition of the product structure on the last process step should maximize parts carry-over. The product structure itself can be reused, as well as most of its components. Only components impacted by the functional enhancement should be changed. If possible, impacted modules and components should be replaced by existing items. This requires an efficient parts classification and a retrieval system. Due to the focus on incremental improvement and information reuse, most of the effort is concentrated on the initial (functional specification) and on the final (product structure deployment) process steps.

The product structuring reference model for release-oriented development is presented in Figure 6. In release-oriented developments, complex products are unitized in release units which are then sequentially and independently released. The functional spectrum is planned for the current and for future states. To consider the interactions between modules synchronization points for future releases have to be defined. The process model differentiates the activities for the development of an entire new product and for the development of a new release of an existing product (Figure 6).

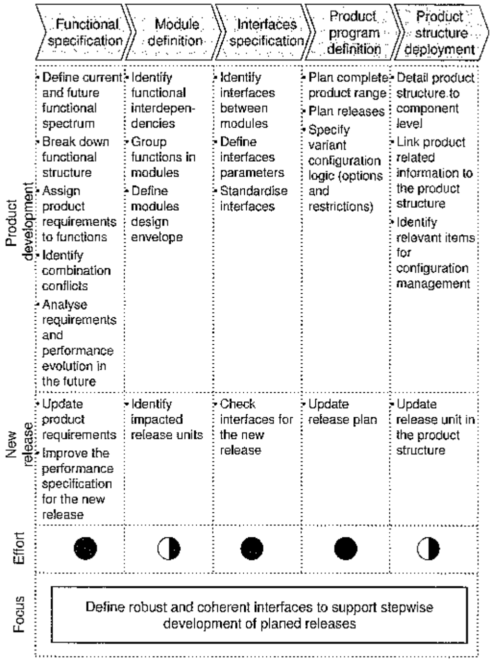


Figure 6: Reference model for release-oriented development.

The products structuring process for a new products to be upgraded in further releases is very similar to the base product structuring process discussed in Section 2. The most significant differences are the evaluation of the future scenarios for requirements and technology at the functional specification phase and the definition of the complete release plan at the program definition phase. The process focus is to define robust and coherent interfaces to support stepwise development of planed releases, allowing product upgrades by exchanging some of its modules.

For every new release, the product requirements should be updated and compared with the initial prevision. The impacted release units have to be identified and the interfaces must be checked. Due to the initial emphasis on interface definition, interfaces should not need to be adapted. A modification on this later stage would lead to high costs. The release plan is updated and finally the release unit is modified in the product structure.

Figure 7 presents the product structuring reference model for add-on development projects. This type of project is based on an existing product which is modified to such an extent that it results in a complete new product based on a new architecture and the use of novel interdependent technologies. The functional spectrum is completely redefined with the inclusion of previously inexistent major functions. Much of the effort is then concentrated on the definition of the product architecture, i.e. the delimitation of the modules and the specification of their interfaces. A base variant is selected for market entry, excluding planning efforts at an early stage. The process focus is to redefine the product architecture while maximizing the reuse of existing information at component level and if possible at process or technology level. Therefore, component carry-over should be maximized while detailing the product structure at component level.

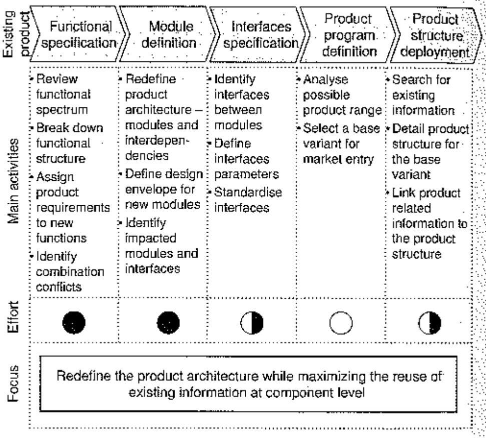


Figure 7: Reference model for add-on development.

The reference model for probe-and-learn development projects is presented in Figure 8. In this kind of project a product is designed for a market segment not yet addressed by the company. Therefore both the product architecture and the technology combination are different from existing predecessors. While structuring the new product the focus should be to maximize the commonality degree at module and component levels. Although the product architecture is new, mostly many existing modules and components can be reused. As the addressed segment is unknown to the company, the requirements for the new product lead to a newly defined functional spectrum. The next step of the product structuring process involves the combination of the newly defined functions in modules. At this point, existing modules should be searched and analysed regarding their applicability in the new product. Minor adjustments in functional parameters not critical to customers can help increase the commonality degree. Considering that the product architecture is completely new, the interfaces specification and standardisation also requires a considerable high effort. The complete product range is defined upfront, but a base variant is selected for further detailing and market entry. At the latest process step further reusable information should be gathered especially at components level. Standard components can be employed even in modules designed specifically for the new product.

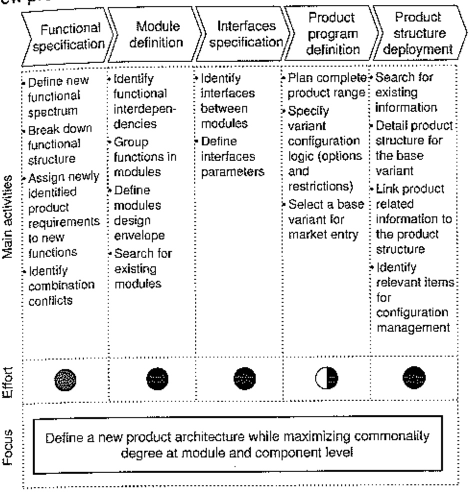


Figure 8: Reference model for probe-and-learn development.

Figure 9 presents the product structuring process for lead-user development projects. In this case the focus is to create radically innovative product architecture and components to address a completely new market segment. The process focus requires high emphasis at the functional specification and the module definition phases. The functional parameters are based on the requirements of lead-users involved since the beginning of the process. A first variant considering these lead-user specific requirements is detailed to component level. As the case may be, the complete product range is further detailed in customer-neutral basic configurations and their variants.

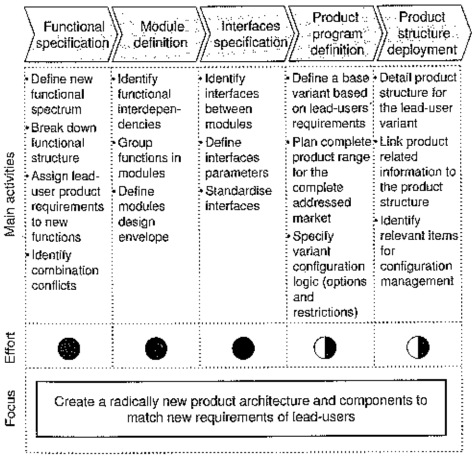


Figure 9: Reference model for lead-user development.

Finally Figure 10 illustrates the product structuring process for tailor-made engineer-to-order projects. Although products are designed to fulfil individual customer needs, the focus should be to maximize the reuse of existing modules and components, as well as previous information in all levels of the product structure. The process begins with the functional specification to address specific customer needs. The further process steps involve partially similar information search and retrieval and partially the detailed specification of customer specific modules. As the product is unique, activities related to program definition are not required.

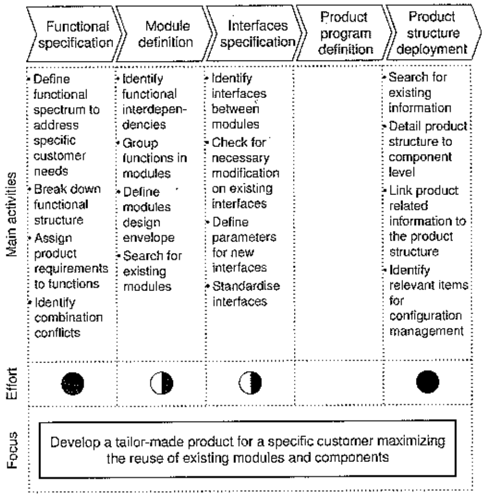


Figure 10: Reference model for tailor-made development.

## 5 EXAMPLES AND BENEFITS

The combinated application of the typology and the set of reference models allows a rapid project initiation based on project information existent beforehand. Thus an efficient and effective approach to product structuring can be guaranteed. Efficient means in this context to focus development acitivities that contribute to the company's strategy. The company's strategy is considered within the development project type. Effective means that the decision that are made within the PLM connex are supported by the right data and are validated.

The step-by-step development (Minimize changes to achieve the desired product performance) of a wind engery mills from an on-shore plant to an offshore-plant required the integration of components within the gondola. The requirements for the components changed slightly since the protection against environmental influences off-shore are stronger than on-shore. The main challenge was the integration of components (for control and transformation) in the gondola that have been placed in the basement of the plant before. After the integration of the components the new structure was valid for the whole assortment.

The release-oriented development of a machine tool spindel represents a modular innovation. The machine tool is modularized at an early stage and the releases are planned. To ensure that new modular innovations are compatible to the interfaces, the definition of the release plan requieres a long-term focus. Interdependencies between the modules have to be considered within the release plan. I.e. a new spindle requires a new numeric and changes control system within the enterprise software. When the next releases are developed, the standardized interfaces are used. Thus the maxim for product structruring in release-oriented development is: Define robust and coherent interfaces to support stepwise development of planned releases.

The add-on development (Redefine the product structure while maximizing the reuse of existing information at component level) of a new fridge/freezer combination with no-frost technology required a complete new structure of the cooling system while the other functions stayed the same. The new concept was to connect freezer and fridge with air flow channels and use one cooling unit. The components and interfaces to change have been identified (e.g. condensors, innerliner) and new components have been defined (air channel, new cooler). The product program has been assessed and the types have been defined according to market entry point.

Example for Probe-and-learn (Define a new product structure while maximizing commonality degree at module and component level) is the development of a new concept for commuter rails. Cost pressure made a concept change from aluminum to steel construction necessary. Additionally new cold-joining technologies have been developed within the project. On the other hand some components from the chassis stayed unchanged. Starting point has been the definition of the product platform till the level of modules. Short development time forced to produce a first product very quickly. From that starting point new variants have been created. Lessons-learned from the first product have been looped back into further platform development.

The development of a new fixing system for pipes and ventilations has been done by using a lead-user development type. After performing studies on lead-user groups the product structure has been designed from scratch to meet the requirements of the lead-user. Basis types have been developed to test the lead-user groups and the entire product program has been planned. Special focus has been set on the configuration logic concerning basis variants, module variants and optional variants. Thus the recommendation for lead-user development can be summarized as: Create a radically new product architecture and components to match new requirements of lead-users.

The tailor-made development is characterized by engineer-to-order. All products are developed individual. The recommendation there is: Develop a tailor-made product for a specific customer maximizing the reuse of existing modules and components. An example is the development of customer-specific highly automated plants for manufacturing contact lenses. Basis for the development is the use of builing blocks for manufacturing lines. Flexibility within the building blocks is necessary to guarentee the usage over different projects. Special product and process know-how is bundeled in process modules that are developed and manufactured customer-specific. Thus, a complete new production line for lenses with new process characteristics has been developed. New similar production lines have been developed on basis of the lessons learned of the first one. The efforts to be spend in product structure is lower in comparison to other development types.

Concerning PLM efficiency it is essential to collect the right amount of information for all product related decisions and activities.

## 6 CONCLUSION

Product Lifecycle Management is getting more and more importance to support management and operational decisions. The product structure is a key element of PLM since it represents the structure for all product related data. Depending on the development type different types of a product structure process have been defined. The types differ within activities and efforts to be spend within certain phases of the product lifecycle. Thus the selection of the right approach to product structuring helps on the one hand to consider all relevant data and process steps within PLM and on the other hand to avoid over-engineered solutions for PLM.

## 7 ACKNOWLEDGEMENTS

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