Approach to structure management and customer-related configuration in the product lifecycle in mechanical engineering

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Abstract. Complexity in the product and production process in mechanical and aerospace engineering leads to the existence of a variety of structures like engineering and manufacturing bills of materials. The manual or partly automated creation of these structures leads to redundant data and quality issues. This paper describes the approach of an integrated structure management based on a reference structure. The development of an integrated reference structure management approach aims to enhance the quality of a product in combination with concurrent complexity reduction. The reference structure is customer- or order-neutral; it is utilized as a basis for other structures. This paper presents a software system-neutral approach for the customer-related configuration of this structure resulting in e- and mBOM. The implementation of the method framework (selection of use cases) in a standard product lifecycle management (PLM) system is part of the research.

1. Structures in the product lifecycle
The product and process complexity in machine and aerospace engineering is increasing daily, not least because of stronger customer orientation and individualization of customer-specific solution packages. In addition, rising quality standards and shortened delivery periods necessitate integrated processes in the product lifecycle combined with a high level of process reliability and stability. In the entire product lifecycle, different fractional structures are created by the involved product lifecycle parties. These multiple product structures [1] reflect the different degrees of product maturity as well as different views of the product (e.g. product development, industrial engineering, project execution, etc.). The different uses of these structures go along with the corresponding perceptions—this result in multiple requirements regarding the management of the structures. Different forms of appearance—requirement lists, bill of materials [2], service instructions, cost structures, among others—can be found in product requirements and functional structures, design and manufacturing structures, and eventually service structures (figure 1).

The origin and development of such structures mostly do not strictly follow a one-way progression. Instead, they arise in iterative processes and are partly dependent on each other, as is the case with spare-part structures based on the design engineering bill of materials. Basically, the degree of maturity and completeness increases with each step forward in the product lifecycle.
The engineering structure (eBOM) is created by product development groups. It represents the so-called ‘as designed’ structure and is mostly customer order-neutral. The eBOM composition represents the multidisciplinary view of the functional definition of the product; it is similar to the 3D CAD assembly structure. The eBOM is usually combined with related product specification documents, CAD models, non-CAD parts (e.g., oil), drawings, and annotations that should give a clear definition of the product. The mBOM [3] is a configuration of the product to show how it will be manufactured, assembled, serviced, and the like. An mBOM typically consists of a structured list of assemblies and sub-assemblies that describe the manufacturing process. This ‘as shipped’ structure is based on the eBOM (it consumes eBOM items). But most of the time, it is not the same as the eBOM because of the manufacturing process and localization.

The mBOM includes the equipment and tools required to build a product’s components. It also includes details of packaging materials, user manuals, and brochures and thereby make the product shippable (figure 2). All these details help the manufacturing team to understand the design assembly and packaging procedures in a better way. The differences between the engineering and manufacturing structures often lead to a big effort in coordination along the creation process. The mBOM is mostly (logically) derived from the appropriate eBOM structure. But in most cases, it is created manually in the ERP or special BOM system—this results in time-consuming activities and errors. Moreover, the manual process makes efficient engineering change management [4] difficult or even impossible.

BOM management [5] is an integrated part of different engineering tools, depending on the kind of the structure. The CAD BOM (design structure) and engineering BOM (eBOM) are often managed in the PDM system. The so-called CAD BOM or design BOM is generated based on the structure in the 3D-CAD system [6]. The CAD BOM can be different than the eBOM (partly due to the modelling-specific CAD structure and partly due to other engineering parts missing in the CAD BOM such as oil). Site-related manufacturing BOMs (mBOM) are mainly managed in ERP systems or in special
BOM management systems. They are mainly derived from the eBOM based on manufacturing and purchasing requirements like extension by semi-finished parts or re-ordering due to the assembly sequence.

2. Analysis of the creation processes of structures
The structure definition process was analysed in the first step of the research. Different types of logic have been identified for the creation of structures, depending on the process initiator.

2.1. Product structure-driven structure definition
This process is mostly used for manufacturing structures similar to or even identical to those of the product structure (eBOM). The definition of the eBOM or eBOM configuration [7] is given in the first step in engineering. Many companies copy their eBOMs and change the structure [8] in the next step, namely manufacturing. The change types are: reorganization of virtual assemblies (creation of new assembly nodes, movement of parts), structure simplification (flattening), structure extension (raw parts, blanks), and part substitution (global vs. local). In some cases, generic mBOM templates are used. These are reconfigured after the eBOM configuration. These processes are eBOM-driven and therefore the main part of the mBOM structure follows the eBOM composition, which is slightly adjusted for local site purposes.

2.2. Manufacturing process-driven structure definition
This process is applied if manufacturing requires structures heavily differing from the initial product structure. An example is the assembly structure, which consists of nodes that represent the local assembly process (for example, assembly steps, parts in the near vicinity). The industrial engineer defines the necessary mBOM nodes in the first step (a new mBOM or based on the mBOM template). For example, in the eBOM, the exhaust manifold is part of the engine compartment. During assembly, however, the exhaust manifold must be added after the body is built on the chassis, since the exhaust pipe must be put through the bumper. This type of regrouping and adding manufacturing-specific parts is most efficiently performed in a separate assembly mBOM structure. EBOM parts (items) are used for the filling of these mBOM nodes in the second step until all parts of the product structure are consumed in the mBOM. The eBOM is not the driver but a ‘part supplier’ for the manufacturing structures in such a way that mainly the parts, and not the structures, are reused. This type of creation mechanism works well for industries in which manufacturing procedures are standardized, such as the automotive or home appliances industries.

3. Approach to the structure management
The core of the new approach is the reference structure (RS), which represents the main framework and rules for communicating operative structures in a globally operating company (figure 3). It neither replaces former structures nor does it serve as an overall information carrier. It rather enables connecting miscellaneous heterogeneous structures and communicating changes faultlessly along the entire product lifecycle. The reference structure allows flexible management of all structures including engineering, logistical, financial, or customer-related structures. This approach is IT-system independent. The reference structure’s appearance, composition, and information contents arise from a context-specific use case, process, and IT application.

The unique structure elements represent the actual reference structure. They serve as connection and interaction points to which operative structure contents or nodes (for example, from a CAD structure or BOM) are assigned to. They store the relations between different operative structure contents at different detail levels. From each unique RS element, it is possible to step into a specific operative structure area (nodes or directly contents) and vice-versa. Following this principle, it is possible to navigate to any operative structure element within the entire product lifecycle via the reference structure. This setup allows the derivation of use case-specific views on the reference structure, including all assigned operative structure contents, by filtering and sorting mechanisms.
Besides the related operative structure data, unique RS elements can directly contain any kind of pre-defined data describing the element, such as CAD data, documents, and cost information or guidelines. This data is usually project-independent and used for standardized product components. RS nodes serve as collection points in the reference structure hierarchy and do not have any relations with the operative structures or pre-defined data. They are not labelled by unique IDs and just combine specific groups and RS elements.

![Reference Structure Diagram](image)

**Figure 3.** Reference structure approach.

For each specific use case (engineering design, manufacturing, project planning, etc.), specific views on the reference structure can be created. The reference structure even allows the derivation of operative structures like visualization structures, manufacturing structures, or CAD structures. This can be done by:

- direct usage: taking over the reference structure or sub structures without changes or with slight simplifications
- extensions/detailing: adding sub-structures (for example, CAD assemblies), additional description of properties, additional referenced data
- simplification: shortening or generalizing the structure composition (for example, for creating the project plan or cost accounting structures)

The reference structure approach can be used for the customer order-related configuration of structures, mainly at engineering (eBOM) and manufacturing (mBOM). The standardized RS elements may already contain pre-defined data, while empty placeholders will be filled with data and related with operative structures during the order-specific product lifecycle. For each product line or product standard in the company’s product portfolio, one RS template should be defined.

### 4. Approach for the customer related structure configuration

In the next phase of the research, an approach to the structure configuration was developed. This approach is system-neutral and therefore can be implemented after the adjustment in data and process-management-engineering IT tools.

Figure 4 shows the approach to the product-structure-driven process. The main part of this process describes the so-called ‘150%’ elements of the reference structure. This ‘product configurator’ contains all possible variants and manufacturing configurations so that a shippable product cannot be built using this structure. Moreover, it contains rules or constraints that determine when the variant items exist in the structures as well as the selections that may or may not be made in combination. This variant logic is combined in configuration set engineering (Ce). The manufacturing process is based on the mBOM logic, which is developed along the same line as that of eBOM and contains all possible configurations for the product parts and the required manufacturing items. MBOM-specific
configuration tasks (e.g. blanks) are defined in the additional configuration set manufacturing (Cm). Both configuration sets are referenced to the reference product structure. In the first step, configuration set engineering is applied to the reference structure. The result is the customer-, project-, or order-related eBOM. The set Cm is applied to the derived eBOM after that so that the eBOM structure is considered. Both sets (Ce and Cm) completely control the mBOM and allow the order-related configuration. Minor adjustments can be done in the final step of the mBOM-creation process.

![Configuration structure](image)

**Figure 4.** Configuration approach.

The developed configuration sets comprise different configuration rules.

- **Options**: The options contain a selection of alternative parts for the reference structure node depending on part conditions and constraints. This pre-developed components defer, for example, geometrically in materials or logistical processes.
- **Part conditions**: These are the main rules for the ‘activation’ of a component. They can contain rules relating to customer requirements, product lines, manufacturing specifications, or local site logistic chains.
- **Local part constraints**: Such constraints define part parameters based on their relations to other components or configuration parameter. For example, the geometric value of a component can be defined in relation to the size of another component.
- **Global part constraints**: Some constraints are defined for the overall company or organization. They are linked with the particular product or configuration. Typical global constraints are based on legal requirements and local customs guidelines or ISO standards, which can lead to the exclusion or inclusion of some components.

5. **Industrial implementation and outlook**

The developed concept was implemented as a prototype for different mechanical products. The engineering systems NX (for CAD modelling) and Teamcenter (product lifecycle management system for engineering and manufacturing) were used. The configuration logic was implemented using a customized configuration for all Teamcenter elements: options, variants, conditions, rule checks, and constraints. The implementation proved the practical relevance and usability of the framework. The primary benefits can be identified in the form of improved quality of product data, consistency of structures, and access to optimized product data.

The developed integrated reference structure management approach aims to enhance the quality of the product in combination with concurrent complexity reduction. Globally operating businesses can only be built on integrated processes as well as on a common understanding of the business and product. To use the reference structure approach, it is essential to realign and harmonize the business processes. When a common process landscape is established and a product consolidation is carried out, the reference structure approach offers an optimal integration instrument. It allows connecting, assigning, and merging of information and processes along the entire product lifecycle. Following the real product lifecycle management (PLM) idea, the reference structure provides the fundamental basis.
for an integration that is not only focused on engineering but on all lifecycle phases. In next phases of the research, advanced structures will be investigated. All requirements structures comprising both customer requirements and internal checklists are very important for the engineering-to-order business. The requirement could be linked with related structure nodes so that the tracking of its fulfilment can be realized. Another set of structures—maintenance service structure or recycling-related structures—emerge at the end of the product lifecycle. The extension will be based on the same basic principle of the central reference structure.

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