Methods for automated semantic definition of manufacturing structures (mBOM) in mechanical engineering companies

Prof. Alexander Stekolschik¹, a
TH Köln, University of Applied Sciences, Betzdorfer Straße 2, Cologne, Germany
³alexander.stekolschik@th-koeln.de

Abstract. The bill of materials (BOM), which involves all parts and assemblies of the product, is the core of any mechanical or electronic product. The flexible and integrated management of engineering (Engineering Bill of Materials [eBOM]) and manufacturing (Manufacturing Bill of Materials [mBOM]) structures is the key to the creation of modern products in mechanical engineering companies. This paper presents a method framework for the creation and control of e- and, especially, mBOM. The requirements, resulting from the process of differentiation between companies that produce serialized or engineered-to-order products, are considered in the analysis phase. The main part of the paper describes different approaches to fully or partly automated creation of mBOM. The first approach is the definition of part selection rules in the generic mBOM templates. The mBOM can be derived from the eBOM for partly standardized products by using this method. Another approach is the simultaneous use of semantic rules, options, and parameters in both structures. The implementation of the method framework (selection of use cases) in a standard product lifecycle management (PLM) system is part of the research.

1. Introduction
A BOM is an extensive list of parts (components), assemblies, raw materials, and linked documents required to describe a product from different points of view (e.g. engineering design, manufacturing, and service). The product structure (BOM) is usually represented in a hierarchical format, with the top level displaying the finished product and the bottom level showing individual parts and materials [1]. The engineering structure (eBOM) is created by the product development groups [2]. It represents the so-called ‘as designed’ structure and is mostly customer order-neutral. EBOM composition represents the multidisciplinary view of the functional definition of the product and 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. MBOM 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 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. Some process-based reasons for the structural differences are (Fig. 1):
- Make or buy decision: Flat BOM structure for outsourced assemblies, including raw parts for insourced parts
- Site-related manufacturing processes: Existing machine fleet or tool sets, specific manufacturing procedures and different staff (NC programmers, operators, etc.)
• Local logistics chain: Deployment of locally procurable materials, raw parts, and suppliers
• Mechanical assembly procedures: Assembly structure based on easy accessibility and assembly order

Figure 1: Examples of eBOM and manufacturing structures

The mBOM includes the equipment and tools required to build the product’s components. It also includes details of packaging materials, user manuals, and brochures that make the product shippable. All these details help the manufacturing team better understand the design assembly and packaging procedures.

The differences between the engineering and the 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 difficult or even impossible [3].

2. MBOM creation process analysis

The mBOM definition process was analysed in the first step of the research. Different logics have been identified for the creation of the structure, depending on the process initiator.

2.1 Product structure (eBOM)-driven mBOM definition

This process is mostly used for mBOMs with structures similar to or even identical to those of eBOM. The definition of the eBOM or the eBOM configuration is done in the first step in engineering. Many companies copy their eBOMs and change the structure in the next step, i.e. manufacturing. The change types are (Fig. 1): 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, which means that the main part of the mBOM structure follows the eBOM composition, slightly adjusted for the local site purposes.

2.2 Manufacturing-driven mBOM definition

This process is applied if manufacturing requires structures that heavily differ from the initial product structure. An example is the assembly structure (Fig. 1), which consists of nodes that represent the local assembly process (e.g. assembly steps, parts in the near vicinity). The industrial engineer defines the necessary mBOM nodes in the first step (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, as the exhaust pipe must be put through the bumper. This type of regrouping and adding of 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 so that
mainly the parts, and not the structures, are reused. This type of creation mechanism works well for industries in which the manufacturing procedures are standardized, such as the automotive or home appliances industries.

In the next step of the research, the requirements of the automated mBOM definition process were defined. The main requirements are common but different mBOM creation process patterns lead to different requirements of the automated mBOM definition process (Table 1).

| EBOM-driven mBOM definition | MBOM-driven definition |
|-----------------------------|------------------------|
| MBOM structure handling (eBOM extension, etc.) without changing the eBOM, independent structure management (versioning, changes) |  |
| Automated deriving of order-related mBOM structure and the possibility for manual actions in the mBOM |  |
| Automated check-consumption usage completeness of eBOM items in the mBOM structure |  |
| A common configuration process for eBOM and mBOM based on the same configuration logics | MBOM-specific (eBOM structure-independent) configuration process |
| Common associative management of configuration rules and options e/mBOM | Management of generic mBOM templates and item selection rules |

3. Approaches for automated semantic definition of manufacturing structures

In the next phase of the research, approaches based on the derived requirements were developed. These approaches are system-neutral so that they can be implemented after the adjustment in data and process-management-engineering IT tools.

Fig. 2 shows the approach for the product-structure-driven process. The main part of this process is the product structure—the so-called ‘150%’ or ‘maxi BOM’ structure. This product configurator contains all possible variant 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 structure, and also, the selections that may or may not be made in combination. This variant logic is combined in the so-called Configuration Set Engineering (Ce). The manufacturing process is based on the mBOM template, which is built similar to the eBOM and contains all possible configurations for the product parts and the required manufacturing items. The structure can be different from eBOM. The Ce is propagated to the mBOM template so that the order-related product configuration drives the option definition in the mBOM and the consumption of the eBOM items. MBOM-specific configuration tasks (e.g. blanks) are defined in the additional Configuration Set Manufacturing (Cm). 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.

Fig. 3 shows the approach for the manufacturing-driven process. The main part is the generic manufacturing structure, consisting only of the main BOM nodes. The mBOM items can be included in the template, but this is not a condition. The generic nodes are extended for the configuration logic, part selection rules (C1, C2, etc.). These rules define which eBOM items should be included in the generic node in the order-related configuration process. The selection rules are based on the properties of the eBOM items (S in Fig. 3). Such properties could be meta-data attributes, part classification, etc. For example, an attribute, ‘assembly unit’, could be defined on an eBOM item so that the mBOM selection rule can identify the required part (e.g. values ‘1’, ‘2’). Another example is the selection based on the part class: mounting parts (screws, bolts) can be identified by the selection rule based on their standard classification (e.g. eCl@ss). The definition of the selection property values in the eBOM structure is done by engineering in accordance with the business process. Some properties can be filled manually by the engineer and some can be a part of the eBOM template. The approach works effectively only if both structures are enriched for the rules and selection properties.
4. Conclusions
The developed process framework was implemented as a prototype for different mechanical products. Engineering systems NX (for CAD modelling) and Teamcenter (product lifecycle management system [4,5] for engineering and manufacturing) were used. The BOM configuration logic, especially in the product-structure-driven approach, was implemented using the customized configuration of Teamcenter elements: options, variants, conditions, rule checks, constraints. The implementation proved the practical relevance and usability of the framework. The main conclusion of the research is that mBOM definition process can be (partly) automated, optimised and speeded up using modern engineering software systems and semantic configuration logic.

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