Research on BOM multi-view mapping method orient to aircraft in-service data management

Shuyu Cai, Die Hu, Yang Fei, Jianxin Xu

College of Aeronautical Engineering, Civil Aviation University of China, Tianjin, 300300, China

*Corresponding author’s e-mail: csy0313@163.com

Abstract. In order to establish the framework for aircraft life-cycle data management and ensure the efficient implementation of maintenance information management of in-service aircraft, the characteristics of maintenance information management of civil aircraft in service were analyzed. BOM views were classified, and a BOM multi-view model was constructed. By analyzing the main mapping forms of BOM multi-views, the node types of BOM multi-view were defined; the mapping rules of BOM multi-view model were proposed, and the mapping algorithm of BOM multi-view model was designed and implemented. Finally, method validation was performed by the BOM mapping of 48-section torsion box of a certain aircraft. The results show that, the mapping of EBOM to M-BOM is realized effectively, ensuring the full integration of the information management structure in the in-service maintenance phase and the development phase, and ensuring the consistency of the aircraft life-cycle data management framework.

1. Introduction
The Bill of Materials (BOM), as the specific manifestation of the product structure\(^1\), carries important product data in various stages of product design, production planning, procurement management, after-sales maintenance and quality management through the whole life cycle of the product. The data storage form of the bill of materials can be identified by the machine, so it is widely used in information systems to describe the technical structure of the products.

BOM multi-view is the reflection of the same product structure at different stages and from different angles throughout the life cycle, the files of which were referred to as "xBOM" by Shatla\(^3\). Wei\(^4\) proposed a multi-view mapping technology for product BOM data based on a single data source, by which the mapping from design BOM to manufacturing BOM was realized. Fu\(^5\) proposed 5 types of BOM view mapping and designed a BOM multi-view data mapping platform under PLM single data source environment. Liu\(^6\) proposed a method of transforming from designing BOM to maintaining BOM and based on this, the construction of MRO system was realized. Zhao\(^7\) proposed an improved method based on public BOM and feature BOM and applied the method to the construction of multi-variable product BOM of construction machinery. Wang\(^8\) proposed a conversion method from design BOM to process BOM and then to manufacturing BOM in the hull manufacturing process. Zhang\(^9\) established the logical relations and mapping rules among product BOM, service BOM and product service integration design BOM respectively based on the product service relevance matrix and BOM mapping theory. Geng\(^10\) proposed a multi-view dynamic management framework to support Dynamic definition and transformation of product structure view.
Lin[11] proposed a conversion method from module-based super BOM to configurable BOM for the demand of bus modular design.

This article is oriented to the in-service phase of civil aircraft, analyzes the characteristics of maintenance data in aircraft operations, defines the M-BOM view model in-service maintenance phase, studies the BOM multi-view model mapping rules, and designs the BOM multi-view model mapping process to achieve the automatic conversion from E-BOM view in aircraft development phase to M-BOM view in aircraft in service phase so as to establish a framework for the management of aircraft life-cycle data.

2. BOM multi-view model design
The in-service aircraft configuration management is aimed at the delivery aircraft operation phase, and it uses the BOM multi-view to continuously track changes in its configuration data to provide corresponding product services and support management.

2.1. BOM multi-view classification
The BOM multi-view of in-service configuration management mainly include: E-BOM, the design and manufacturing stage bill of materials, is the source of all forms of BOM during the aircraft's entire life cycle; S-BOM, service bill of materials, which is the bill of materials for aircraft support configuration management by manufacturer customer service department, is the transition from the in-research aircraft configuration management to the in-service aircraft configuration management.; M-BOM, maintenance bill of materials, is the bill of materials for the aircraft maintenance process configuration management by the operator's maintenance department.

E-BOM describes the attribute characteristics of engineering parts and assemblies through the physical structure relationship of the aircraft, is a requirement for product materials in the design and development stage, including a list of all assembly sub-assemblies, standard parts and components on the physical structure of the aircraft, and the level and assembly quantity relationships among all materials.

S-BOM is used for the configuration management of the same batch of aircraft support projects, mainly including information on aviation material resources, maintenance engineering support, flight operations support, technical publications, and training support.

M-BOM not only describes the material information required in aircraft maintenance activities, but also is the product structure organization of the maintenance department driving maintenance business and maintenance needs. Due to the obvious individual differences in the operation and maintenance of each aircraft, M-BOM manages data in the form of stand-alone product structure, including maintenance business information (maintainability, life span, inspection cycle, work type, etc.), maintenance data and knowledge, and peripheral material information (maintenance tools, tooling).

2.2. BOM view model
E-BOM, S-BOM, and M-BOM can be designed as a three-layer tree structure, that is, the top layer, the function layer, and the bottom layer. Their top layer structure is basically the same, and there are obvious differences between their function layer and the bottom layer.

The functional layer of E-BOM is the classification of the assembly module of the physical structure of the aircraft; the functional layer of S-BOM and M-BOM is the configuration layer. The BOM configuration item is the service configuration item, the definition scope of which is maintenance engineering support, flight operation support, aviation materials Checklist and support, training materials and courseware, technical publications, etc. The configuration data module of S-BOM configuration item is a service solution, and its associated object indicates the effectiveness of the order. The M-BOM configuration item is a maintenance configuration item, the configuration data module of which is a maintenance solution and the associated object of which is a station.
The bottom layer of E-BOM describes the assembly of each major component in detail; for S-BOM, the bottom part is no longer a focus and is set as a virtual layer; the bottom layer of M-BOM does not need to be expanded to the part level for the part of the line replaceable parts.

Fig.1 BOM multi-view model structure relationship

2.3. BOM view model definition

Define $B^X$ as the BOM for phase $X$, where the value of $X$ is $E$, indicating the engineering phase; $S$ indicates the customer service phase; $M$ – indicates the maintenance phase.

$B^X$ model can be represented by five-tuple $(A^X, C^X, Q^X, P^X, V^X)$. That is $B^X = (A^X, C^X, Q^X, P^X, V^X)$. Among them, $A^X$ is a collection of all components, where $a_i (i = 1, 2, \cdots)$ mean number $i$ record of BOM corresponding parts;

$C^X$ is assembly relationship set for parts, where $c_i$ represent the superior assembly relation of $a_i$ and “.” means no superior;

$Q^X$ is a collection of component assembly quantity descriptions;

$P^X$ is a set of attributes $p_{ij} (j = 0, 1, 2, \cdots)$ for parts $a_i$ and $p_{i0}$ are node type attributes;

$V^X$ is a set of attribute values $v_{ij}$ corresponding to attribute $p_{ij}$ of parts $a_i$. 

The functional layer

Structure of The Bottom Layer

Parts

- List of assembly subparts, standard parts and parts, etc.
- Material Quantity and Hierarchy Relationship

Module

ATA Chapter

Service configuration items

Data M module (Service Solution)

Maintenance configuration items

Data Module (Service Solution)

Maintenance support information

Data Modules

Not detachable assemblies

Detachable assemblies
3. BOM multi-view mapping rules

3.1. Mapping process analysis from E-BOM to M-BOM

E-BOM and M-BOM have different assembly relationships between components and parts. E-BOM reflects the assembly relationship on the physical structure of aircraft products. M-BOM attaches the aircraft product structure to the management of product maintenance business information.

The main variation of the E-BOM to M-BOM mapping is shown in Fig. 2.

a) The structure is unchanged

b) The structure is expanded

c) The structure is truncated

d) The structure is changed

Fig. 2 The mapping form from E-BOM to M-BOM

(1) The mapping structure is unchanged. The top-layer structure information of M-BOM and E-BOM has high consistency. This area is an invariant structure during the mapping process, and the nodes are defined as inherited nodes.
The mapping structure is expanded. During the maintenance, the assembly parts in the EBOM are divided and disassembled, which makes the structure of the MBOM relative to the EBOM detailed to the node of the maintenance process. Define the refined nodes as key nodes.

(3) The mapping structure is truncated. For parts such as replaceable parts of the route, only the entire component needs to be replaced without being split during maintenance. Therefore, M-BOM does not need to be expanded to the bottom part layer of E-BOM. Define the nodes as omitted nodes.

(4) The mapping structure is changed. The maintenance configuration item defined in the M-BOM configuration layer is not a real physical component. For example, in the M-BOM, the sub-node below the "composite material maintenance record" node is composed of "radome", "vertical tail" and "fuselage skin" in EBOM. Define the nodes as combination nodes.

### Table 1 Node type definition

| Node type       | Symbol | Definition                                                                 |
|-----------------|--------|----------------------------------------------------------------------------|
| Inheritance node| $C_L$  | Node structure remains unchanged during E-BOM to M-BOM mapping              |
| Key node        | $C_K$  | Nodes subdivided when mapping from E-BOM to M-BOM                         |
| Omit node       | $C_E$  | There are nodes in E-BOM that do not exist in M-BOM                       |
| Combination node| $C_C$  | Multiple nodes combined into one node when mapping from E-BOM to M-BOM    |

3.2. Mapping rules

(1) Inheriting node mapping rules ($F_L$)

If nodes $v_i = C_L$, then:

$$\begin{align*}
    A^M \cdot \text{ADD}(a_i) \\
    C^M \cdot \text{ADD}(c_i) \\
    Q^M \cdot \text{ADD}(q_i)
\end{align*}$$

Continue the traversal.

(2) Key node mapping rules ($F_K$)

If nodes $v_i = C_K$, $a_j$ are assembly components of $a_i$, there are:

$$\begin{align*}
    A^M \cdot \text{ADD}(a_i), & A^M \cdot \text{ADD}(new \, a_i) \\
    C^M \cdot \text{ADD}(c_i), & C^M \cdot \text{ADD}(new \, c_i) \\
    Q^M \cdot \text{ADD}(q_i), & Q^M \cdot \text{ADD}(new \, q_i)
\end{align*}$$

(3) Omit node mapping rules ($F_E$)

If nodes $v_i = C_E$, $a_j$ are subordinate components of $a_i$, there are:

$$\begin{align*}
    A^M \cdot \text{ADD}(a_i) \\
    C^M \cdot \text{ADD}(c_i) \\
    Q^M \cdot \text{ADD}(q_i)
\end{align*}$$

$a_i$ based deep traversal ends.

(4) Combined node mapping rules ($F_C$)

If nodes $v_i = C_C$, then:

Firstly, traverse to determine the set of combined nodes.
Suppose the current nodes are \( a_i \), satisfy \( v_{j0} = C_c \), then \( a_j \) join the combined node set; traverse to determine the nodes \( a_j \), satisfy \( c_j \text{ LIKE } '\%k' \), \( v_{j0} = C_c \); that is, \( a_j \) are the combination nodes connected with \( a_j \); suppose \( a_j \) are the current nodes, \( a_j \) join the combined node collection and then loop through it.

Combined node processing.

Suppose the combined node set is \( \{ a_i \} \), the combined nodes in m-BOM are \( a_m \).

\[
\begin{align*}
A^M &. ADD( new \ a_m ) \\
C^M &. ADD( new \ c_m ), c_m = \max_k \{ c_k \} \\
Q^M &. ADD( new \ q_m ), q_m = q_N, N = \min_k \{ c_k \}
\end{align*}
\]

Structural Adjustment of Relevant Nodes.

Traverse to determine nodes \( a_i \), satisfy \( c_i \text{ LIKE } '\%k' \), i.e. the lower nodes of the combined node. Replace \( c_i \) in \( k \) with \( m \).

4. BOM Multi-View Mapping Algorithm Process

The BOM multi-view mapping algorithm process is based on the breadth-first traversal strategy to achieve the mapping from E-BOM to M-BOM.

(1) Take the node where \( c_i = \cdot \) as the first node of the traversal;

(2) According to the value of \( v_{j0} \), judging the current node type, and process it according to the corresponding mapping rules (1) ~ (4), and mark the current node as traversed;

(3) Traverse the unlabeled adjacent vertices of the current node in turn, and turn to (2);

(4) If there are nodes that are not marked, select \( \min c_i \) node as the current node, and turn to (2);

(5) All nodes are marked, then it ends.

![Fig.3 Mapping algorithm process from E-BOM to M-BOM](image-url)
5. Example verification
In order to verify the BOM multi-view mapping algorithm for in-service aircraft configuration management, a 48-section torque box BOM of an aircraft is selected as an example, as shown in Fig.4. The M-BOM is obtained according to the mapping algorithm, and the mapping result is shown in Fig.5.

Fig.4 48 segment torque box E-BOM
In this example verification, the stiffener node is an inherited node, and its corresponding structure in E-BOM and M-BOM is the same. The torque box node is a key node, and two-level assembly sub-assemblies are created when it is mapped to M-BOM, the part number of which is 148a8600-2-902, 148a8600-2-901. The corner brake nodes and panel nodes are combined nodes, the structure of which is unchanged and positioned to the lower level of the second-level assembly sub-component.

6. Conclusion

This paper defines the BOM multi-view model, analyzes the main BOM multi-view mapping form, and proposes the mapping rules of the BOM multi-view model for different node types of the BOM multi-view, and designs the BOM multi-view model mapping algorithm. Verified by examples, it can be seen that the definition of the BOM multi-view model guarantees the hierarchical connection between aircraft in-service information management and aircraft R & D information management, and the BOM multi-view model mapping method realizes the mapping transformation of E-BOM to M-BOM, ensuring the completeness, consistency and traceability of the in-service data management framework.

Acknowledgments

This paper is supported by the Fundamental Research Funds for the Central Universities of CAUC. The project number is: 3122017026.

References

[1] Peng Y, Gong J X, Huang K D. Research on Reuse-oriented similarity evaluation of BOM conceptual model[J]. Journal of National University of Defense Technology, 2011, 33(2): 113-118.
[2] Srinivasan V. An integration framework for product lifecycle management[J]. Computer aided design, 2011, 43(5): 464-478.
[3] Wei MU, Chun-liu ZHOU, Hong-guang BO, Jun-yi LIANG. A Bill of Material Transformation Method for Design-Manufacturing Integration[P]. DEStech Transactions on Engineering and Technology Research, 2016.
[4] Wei Zhiqiang, Wang Xianyu, Wu Dan, et al. Multi-view mapping technology of product BOM based on a single data source [J]. Journal of Tsinghua University (Science and Technology), 2002, 42 (6): 802-805.
[5] Qiuhong F, Ruizing Z, Qun W, et al. BOM Multi-view Mapping Based on a Single Data Source
under PLM[C]// Proceedings of the 2012 International Conference on Industrial Control and Electronics Engineering. IEEE Computer Society, 2012:1705-1708.

[6] Liu M, Lai J, Shen W. A method for transformation of engineering bill of materials to maintenance bill of materials[J]. Robotics and Computer-Integrated Manufacturing, 2014, 30(2): 142-149.

[7] Zhao Changsheng, Jiang Liyong, Dong Songjin, et al. An improved method for BOM construction of multi-variable products [J]. Manufacturing Automation, 2013, 35 (2): 113-115.

[8] Wang Y, Meng M. Integrated model and mapping technology of BOM multi-view for Hull block manufacture[C]// Computational Sciences and Optimization (CSO), 2012 Fifth International Joint Conference on. IEEE, 2012:113-117.

[9] Zhang Jianmin, Zhou Jun. Research on design methods of mechanical and electrical products based on ssdp / pss [j]. Light Industry Machinery, 2017, 35 (1): 95-101.

[10] Geng Jianguang, Cai Chengzhi, Ni Yongquan, et al. Design and implementation of a multi-view dynamic management framework for product structure [J]. Modern Manufacturing Engineering, 2015 (11): 45-50.

[11] Lin Xiaorong. Modular design of bus and application of super bom [j]. Mechatronics Technology, 2019 (2): 116-120.