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Research article

Research on the integrated management and mapping method of BOM multi-view for complex products

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Abstract: The bill of materials (BOM) runs through all stages of the life cycle of manufacturing products, which is the core of manufacturing enterprises. With increasing complexity of modern manufacturing engineering and widespread using of intelligent manufacturing technology, the BOM data keeps rising and transformation process is increasingly frequent and complicated. In order to improve efficiency of BOM management and ensure the diversity, accuracy and consistency of BOM in the product development, the BOM multi-view integrated management and mapping method for complex products were researched. First, a complex product BOM integrated management framework and the evolution model based on multiple views were established which described the BOM integrated management mechanism and transformation relationship among different BOMs. Subsequently, process of BOM transformation was analyzed, and a BOM transformation model was proposed. Moreover, a rule-based BOM multi-view mapping algorithm was proposed. With the rule definition and mathematical modelling for key components, the complex mapping principle was elaborated. Finally, the BOM multi-view transformation cases and the prototype system were illustrated and discussed, which verified the feasibility and versatility of model and method.

Keywords: computer-integrated manufacturing; bill of materials (BOM); rule-based mapping; multi-view; BOM transformation

1. Introduction

With the widespread application of enterprise informational and intelligent manufacturing technology, as the core of enterprise product data, bill of materials (BOM) has gradually become the key to enterprise information integration [1]. BOM almost connects the production activities of various departments of the enterprise, including design, process, manufacturing, purchasing, sales and so on. It has laid the foundation for a new type of production organization and makes the production management of manufacturing enterprises more scientific. The concept of BOM [2] has also been extended to the full life cycle of the product with the development of technologies such as CAD, PDM, CAPP and ERP. At different stages of the product life cycle, the product structure will have a corresponding BOM type, and the basic forms are design BOM (EBOM), process BOM (PBOM) and manufacturing BOM (MBOM). On the basis of these BOMs, packing BOM, sales BOM, maintenance BOM, etc. are also derived. They not only improve the transparency of design, process and manufacturing data, but greatly promote the seamless integration and sharing of product data.

However, with the increasing complexity of modern engineering and constantly changing of market demands, the BOM data is growing rapidly, interaction frequency among various BOMs is also higher and higher. Usually, EBOM, PBOM and MBOM are the basic sources of the subsequent ERP system, and these BOMs exist in different stages of the product. From the management perspective, these BOMs can be managed in the PLM / PDM system. However, it can also bring some problems. If PLM / PDM system saved the various BOMs at the same time, it would appear that the same material code has different forms of expression, which would also bring disruption for subsequent system integration and product development. Additionally, if not to ensure the diversity, accuracy and consistency of BOM, these factors will directly or indirectly affect collaboration, integration and transformation of product BOM. Moreover, it would also bring other problems such as increasing product costs and extending development cycles and even reduce market competitiveness of enterprises.

Therefore, this paper proposes a rule-based BOM multi-view integrated management and mapping method for complex products. The research contents are as follows: Section 2 summarized and analyzed the current related research work of BOM; Section 3 constructed a complex product BOM multi-view management architecture and BOM evolution model; Section 4 elaborated key means and technologies in framework; Section 5 verified the proposed mapping method by transformation examples of core views about EBOM, PBOM and MBOM; Finally, the paper has been summarized and prospected.

2. Related work

With growing market competition, the product life cycle continues to shorten and product structure has become more and more complex. BOM has been gradually prominent for the reason that it's associated with product data. The informational and intelligent technologies [3] have been applied on a large scale in enterprises, but it's not easy to achieve unified and integrated management of BOM. Above all, the BOM information is usually distributed in various systems. Furthermore, BOM types continue to expand. Moreover, there are transformation relationships among distinct BOMs. These make enterprises confront with great suffering in BOM management. Therefore, in response to the above problems, a multitude of researches have been indicated as below.

2.1. Full life cycle management of BOM

A BOM is a list of all parts, ingredients or materials which can make one product. The data organization and representation style for a BOM is called the structure of the BOM or the product structure [4]. Currently, BOM management has gradually extended from a single narrow concept to various forms, forming a full life cycle BOM structure.

Liu [5] and Huang [6] proposed an XBOM management plan for the life cycle of product. The BOM was defined as EBOM, PBOM, MBOM, procurement BOM, cost BOM and quality BOM, etc. Xiang [7] presented the energy consumption bill of materials (ECBOM) with combining information technology with green manufacturing theory, which is similar to MBOM or other extended BOM for different business scenarios. Zhou [8] considered static service BOM (SBOM) to establish product data for providing effective maintenance, repair and overhaul service. In addition, something about BOM version management [9–13] have also been researched.

2.2. BOM multi-view mapping

With rising complexity and dynamics of modern product, BOM data continues to increase, BOM types also keep on expanding. These make transformation process be-tween different BOMs gets complicated. In order to ensure the diversity, accuracy and consistency characteristics of BOM in type transformation process, BOM multi-view mapping has gradually become a research hotspot, corresponding researches have been constantly carried out.

Xia [14] presented a mapping method for BOM multi-view, which could record all the mapping parameters of all kinds of BOM through transforming-table to accomplish mutual transformation among different BOM views. Cai [15] put forward mapping rules of BOM multi-view model, and the mapping algorithm of BOM multi-view model was designed and implemented. Zhang [16] proposed a BOM view transformation method based on view matching algorithm, which is to achieve efficient transformation of the assembly BOM by reusing the BOM structure. Wei [17] discussed a multi-view mapping technology for product BOM data based on a single data source, analyzed the data mapping relationship between the BOM multiple views, and designed the BOM multi-view data mapping platform. Yan [18] studied the mapping method of BOM multi-view, the domain-oriented mapping relationship model and transformation space model were constructed. Liu [19] considered the BOM transformation method based on feature recognition and corresponding mapping model had been deployed into an MRO system for a steel manufacturing enterprise. Liu [20] proposed a method of BOM multi-view mapping based on configurable rules, model of BOM multi-view and transformation process was also constructed. Jiang [21] and Wang [22] had also paid more attention to PBOM and probed the view mapping strategy from EBOM to PBOM.

2.3. Summary

The BOM has performed prominent role in modern intelligent manufacturing. Product data is gradually organized and managed by BOM, the full life cycle BOM is presented to form diverse BOM types such as EBOM, PBOM, MBOM and so on. How-ever, how to manage these BOM types in a unified manner to ensure the consistency, effectiveness and completeness of product data in the life cycle requires further research.

Some mapping means of BOM multi-view transformation have also been proposed to achieve information integration in the product life cycle, which can be summarized into feature recognition, view matching, configuration rules and process management etc. These methods have achieved fantastic results to a certain extent, but the universal regularities of BOM transformation need more to be regarded. In addition, they focus more on BOM multi-view transformation in design and process, something mapping in manufacturing stage are considered less.

Therefore, combining with researches above, the paper proposed the corresponding architecture, model and method for BOM multi-view integrated management and mapping transformation for complex products, which would be indicated as follows.

3. The BOM integrated management and evolution framework for complex products based on multi-view

The development of the product has gone through different stages and departments and will form a variety of BOM. The type of BOM determines sort of BOM view, there are relationships of upstream and downstream in kinds of BOMs. EBOM provides basic material items of product, which is foundation of other BOM. Therefore, the material items in EBOM will inevitably appear in PBOM, MBOM and other BOMs. Moreover, the required quantity of these material items in the entire product hardly change in the BOM transformation process. The BOM multi-view evolution model in manufacturing process of complex products is shown in Figure 1.

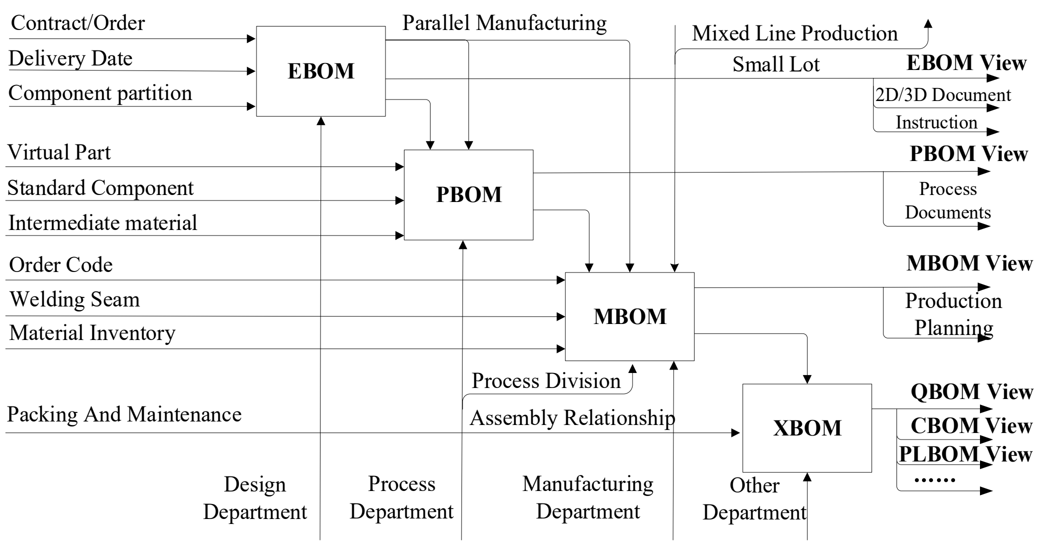

Figure 1. BOM multi-view evolution model.

On the perspective of product structure, EBOM is generated by the design department according to customer orders or design requirements which usually contains contract, delivery date, component partition and so on information. Based on EBOM, PBOM is obtained in the process department by process decomposition which mainly indicates the process route and facilitates the processing cost management measurement, etc. It plays an important role in process design and manufacturing. In addition, virtual parts, outsourcing/standard parts, intermediate parts would be added. According to manufacturing process, process division and assembly relationship, MBOM is acquired by re-establishing relationship of material items of PBOM in the manufacturing department, which mainly describes the assembly sequence of the product, the labor manhours, material ration and the related equipment, tools and so on. Then, MBOM can also derive a variety of other BOMs for other departments.

Based on the manufacturing and assembly relationship of MBOM, the rest BOMs will be formed by other departments which represented by XBOM in the diagram. Quality BOM was formed by adding quality control information and measured quality data. The production department makes production plans based on MBOM and forms Planning BOM to guide production and machining. The supply department develops procurement plans based on MBOM and generates purchase BOM. The financial department also generates Cost BOM based on MBOM to perform cost accounting, sets prices and so on. In the product life cycle, different BOMs are generated by different departments resulting in different BOM views, thus BOM multi-view will also be constantly evolving with BOM transformation.

In the manufacturing process of complex products, distinct BOM corresponds to respective stage of product production, and can be indicated by BOM multi-view. The BOM information is constantly changing with progress of manufacturing process, and the transformation among BOMs also reflects mutual communication and collaboration between different departments of enterprises [23]. The collection of all the BOM views can illustrate complete information of product life cycle.

The product structure will provide related BOM to serve the corresponding business at each stage of product life cycle, various users can create, use and maintain domain data by BOM multi-view according to business requirements. The BOM multi-view integrated management framework of complex products is shown in Figure 2.

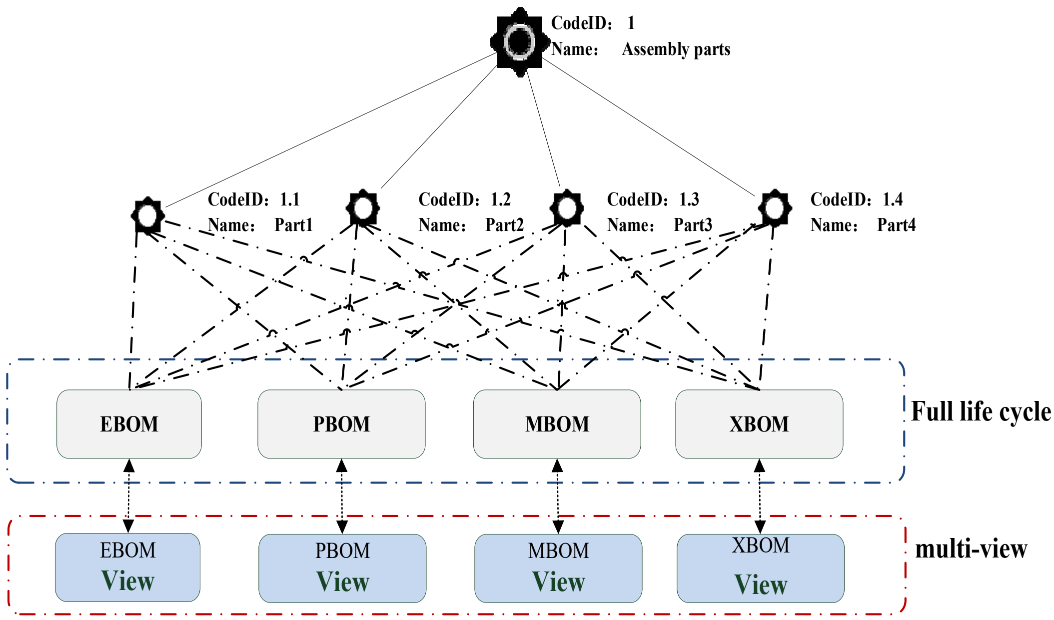

Figure 2. The BOM multi-view integrated management framework.

Currently, many manufacturing enterprises have implemented PDM/PLM systems, and EBOM, PBOM and MBOM are usually managed by PDM. During product design development, designers would build EBOM in PDM system for each part drawing as a BOM node, which provides the basis for subsequent PBOM and MBOM generation.

The process department uses the published EBOM in the PDM system to generate the structure snapshot, fill in the corresponding process attributes on the snapshot as well as add or adjust some process routes, such as adding or deleting nodes to the structure snapshot, making specific refinements or changing the materials in the design department. At the same time, the process designers can utilize CAPP to make process cards and extract the card information to PDM. After these operations, the PBOM is generated without changing the EBOM.

Similarly, the manufacturing department can apply the published PBOM to generate the corresponding structure snapshot directly to generate MBOM by adding some production attributes and changing the production type of some materials. MBOM would be also imported into ERP for production through data integration.

Moreover, EBOM, PBOM, MBOM and other BOMs will exist independently in the PDM at the same time in the most enterprises, it is convenient for each department to maintain corresponding BOM data. However, if there was a lack of effective cooperation among departments, it would make the upstream and downstream data appear disconnected, for example, the same material code has different names, forming data silos and resulting in data inconsistency, further enhancing the difficulty of data integration. In order to solve above problems, these data have to be organized into a logically single data storage entity, and strict constraints are established to form single source of product data [24]. Thus, the unified BOM model based on single source of product data is created as shown in the following Figure 3.

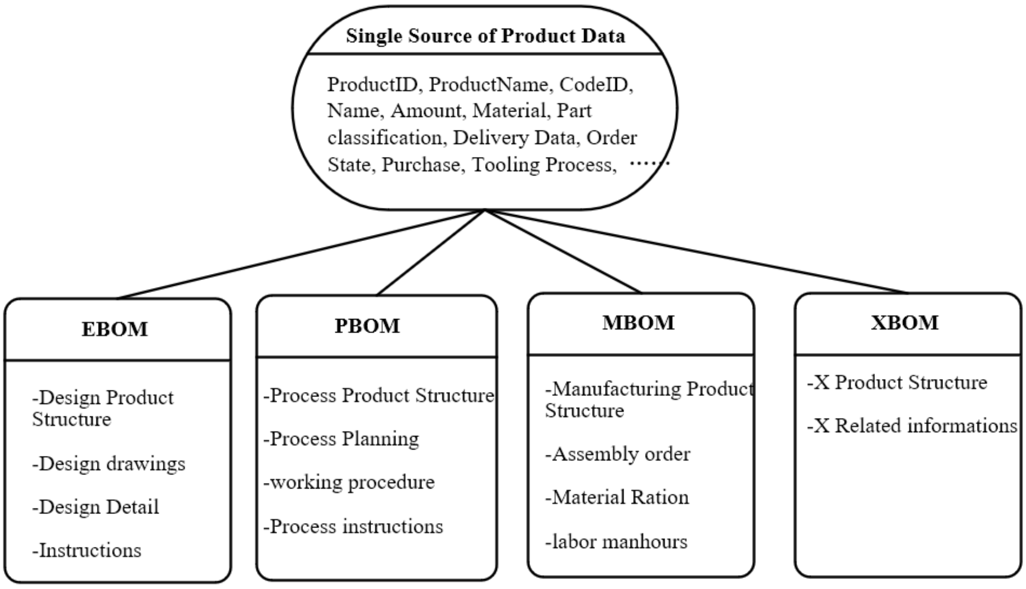

Figure 3. The unified BOM model based on single source of product data.

As a single data source, product data contains basic information such as product ID, product name, part ID, part name, amount, material, part classification, delivery date, order status, purchase and tooling data, etc. Usually, product development starts with EBOM, and single data source is generated synchronously when EBOM is built. Subsequently, as development progresses, the single data source will also interact with other BOMs, which provides source support to ensure the accuracy and consistency of the BOMs.

In the EBOM, PBOM, MBOM and XBOM, different information is contained. For example, in the EBOM, the design product structure, design drawings, design detail and instructions are included. In the PBOM, design product structure, process planning, working procedure, process instructions and so on are involved. Similarly, the MBOM and XBOM also incorporate the corresponding information. Thus, the diversity of BOMs is reflected.

In various BOMs, there are corresponding product structures, whose nodes information reference the single data source. For example, EBOM contains the design product structure, PBOM includes the process product structure, MBOM holds the manufacturing product structure, etc. BOM multi-view have a close relationship with product structure. The product structure runs through all stages of product life cycle, and each stage can be indicated in various forms. With the BOM transforming, product structure will keep changing, and the corresponding BOM view will also alter. The mapping methods of BOM multi-view will be discussed in the next section.

Furthermore, the BOM multi-view can illustrate distinct expressions of product structure at various stages of the product life cycle. Figure 2 shows the three main types of EBOM, PBOM and MBOM as well as extension types XBOM (X can represent multiple business). In order to facilitate the control and maintenance of product data, the framework will supply related BOM views.

Therefore, various product data are aggregated, displayed and managed in corresponding BOM view. For instance, EBOM view will be associated with design data, and PBOM view will be associated with process specification files. Engineers in various regions can independently access and manage product data and business information by using corresponding BOM view. Meanwhile, cooperating with reasonable version control mechanism to ensure product data is consistent, complete and reliable.

4. Rule-based BOM multi-view mapping algorithm for complex products

4.1. Parts classification in BOM multi-view mapping

In the BOM multi-view mapping process, there are various methods for different types of parts. For example, parts that cause the difference between EBOM and PBOM are mainly core parts and outsourcing parts, while other parts that cause the difference between PBOM and MBOM are mainly virtual parts and intermediate parts. In BOM multi-view mapping, the difficulties and key points would be focused on these special parts. There are 5 classifications involved in BOM multi-view mapping, described as follows:

Heredity part: It refers to the part whose assembly relationship in MBOM is exactly the same as that in EBOM and PBOM.

Core part: Core part can continue to be subdivided to specific parts as result of rough division in process decomposition.

Outsourcing part: It represents that the part requires outsourcing for itself and all its subordinate parts, which exists fully in EBOM. However, in MBOM, it only needs to be regarded as an independent module. There is no requirement for detailed information, only the production type is described as outsourcing. Meanwhile, the company mayn't need to compile process documents.

Virtual part: It means that part is recorded in EBOM, but wasn't manufactured and stored in actual production. Virtual component has no corresponding records in MBOM.

Intermediate part: The intermediate part does not exist in EBOM, but it needs to be stored in actual production. It's reason that some parts need to be temporarily installed together during assembly process, which generally break corresponding assembly relationship of product structure.

4.2. Mathematical modelling of BOM multi-view mapping

In order to accurately and conveniently reflect the BOM multi-view mapping relationship, it is necessary to establish the mathematical model for product, parts and assembling relation.

Set *p* (part node) is a description of a certain part node in the product, mainly including the relevant attributes and identification of part in product structure. Additionally, *P* (Product collection) represents set of all nodes in a certain product, which can be defined as:

$$P = \{p_1, p_2, p_3, \cdots p_n\} \tag{1}$$

Set R means assembly relationship between part nodes, which can be defined as:

$$R = [f, c, q], f \in P, c \in P, q \in Z \tag{2}$$

where:

When $q > 0$, there is the direct parent-child relationship between node *f* and node *c*, and *f* is the parent of *c*, the assembly quantity is *q*.

When $q < 0$, there is also the direct parent-child relationship between *f* and *c*, and *c* is the parent of *f*, the assembly quantity is $-q$.

When $q = 0$, there isn't the direct parent-child relationship between *f* and *c*, there is no assembly relationship.

Set *Tr* (Tree of product structure) contains the information and relationships of all nodes in product structure, which can be defined as:

$$Tr = \{P,\ R_{Tr}\} \tag{3}$$

where:

$P = \{p_1, p_2, p_3, \cdots p_n\}$,

$R_{Tr} = \{R_i = [f_i, c_{ij}, q_{ij}]\}$, $i \in n, f_i \in P, c_{ij} \in P$; c_{ij} is a child node of f_i.

What's more, in BOM multi-view mapping process, *R* would involve in some operations including addition operation, subtraction operation, multiplication operation, permutation operation and elimination operations, as shown below:

Definition 1: Addition operation:

$$[f_i, c_i, q_{1,}] + [f_i, c_{i,} q_2] = [f_i, c_{i,} q_1 + q_2] \tag{4}$$

Definition 2: Subtraction operation:

$$[f_i, c_i, q_1] - [f_i, c_{i,} q_2] = [f_i, c_{i,} q_1 - q_2], \text{and } \ q_1 > q_2 \tag{5}$$

Definition 3: Multiplication operation:

$$k \cdot [f, c, q] = [f, c, kq],\ k \in Z \tag{6}$$

$$-[f, c, q] = [f, c, -q] = [c, f, q] \tag{7}$$

Definition 4: Permutation operation:

$$\overrightarrow{\mathrm{p,f}}[\mathrm{f,c,q}] = [\mathrm{p,c,q}] \tag{8}$$

From subtraction operation, it can be deduced:

$$\overrightarrow{\mathrm{p,c}}[\mathrm{f,c,q}] = \overrightarrow{\mathrm{p,c}}[\mathrm{c,f,-q}] = [\mathrm{p,f,-q}] = [\mathrm{f,p,q}] \tag{9}$$

Definition 5: Elimination operation:

$$[\mathrm{f\ c_i,q}] \otimes \{[\mathrm{c_i,t_{ij},q_{ij}}]\} = \{[\mathrm{f,t_{ij},q \cdot q_{ij}}]\} \tag{10}$$

4.3. Rule-based BOM multi-view mapping algorithm

BOM multi-view mapping is triggered by nodes change. Since heredity parts do not make structure alter, no mathematical operations are required. Therefore, aiming at BOM multi-view mapping, above mathematical definitions can be combined to provide corresponding mapping methods based on rules of core part, outsourcing part, virtual part and intermediate part. Assuming that the state of structure tree can be expressed as $Tr^o = \{P^o, {R^o}_{Tr}\}$ before mapping, the specific mapping rules are as follows.

4.3.1. Mapping rule for core part

If *p* is the core component, the information of sub-nodes and assembly relationship needs to be supplemented for PBOM based on EBOM, which belongs to derivative mapping. mapping rule can be defined as:

$$\mathrm{f_c(p)} = \{\mathrm{P^o} + \{\mathrm{p_{cj}}\}, \mathrm{R^o}_{\mathrm{Tr}} + \mathrm{R_{apc}}\} \tag{11}$$

where:

$\mathrm{p_{cj}}$: Child node added for p;

$\mathrm{R_{apc}} = \{[\mathrm{p, p_{cj}, q_{cj}}]\}$: Set of relationships between p and children nodes added;

$\mathrm{q_{cj}}$: Assembly quantity of p and sub-node added.

4.3.2. Mapping rule for outsourcing part

If *p* is the outsourcing part, it needs to delete sub-nodes and assembly relationship information contained in EBOM, which belongs to distribution mapping. The mapping rule can be defined as:

$$\mathrm{f_o(p)} = \{\mathrm{P^o} - \{\mathrm{p_{cj}}\}, \mathrm{R^o}_{\mathrm{Tr}} - \mathrm{R_{opc}}\} \tag{12}$$

where:

p_{cj}: Child node deleted for p;

$R_{opc} = \{[p, p_{cj}, q_{cj}]\}$: Set of relationships between p and children nodes deleted;

q_{cj}: Assembly quantity of p and sub-node deleted;

If there are sub-nodes under child node, it must continue to apply iterative loop until completely deleted.

4.3.3. Mapping rule for virtual part

If *p* is the virtual part, it needs to delete p in PBOM, and move all children nodes up, meanwhile multiply assembly quantity, which refers to derivative mapping and aggregation mapping. The mapping rule can be defined as:

$$f_v(p) = \{P^o - p, \overrightarrow{p_f, p}R^o{}_{Tr} + (q_f - 1)\overrightarrow{p_f, p}R_{vpc} \tag{13}$$

where:

p_f: Parent node of p;

q_f: Assembly quantity of p and parent node;

$R_{vpc} = \{[p, p_{cj}, q_{cj}]\}$: Set of relationships between p and children nodes;

p_{cj}: Child node for p;

q_{cj}: Assembly quantity of p and sub-node;

4.3.4. Mapping rule for intermediate part

If *p* is the intermediate part, the corresponding assembly relationships should be supplemented to the MBOM according to PBOM information, which involve in derivative mapping and aggregation mapping. The mapping rule can be defined as:

$$f_I(p) = \{P^o + p, R^o{}_{Tr} + R_{Ipf} + R_{Ipc} - R_{Ipf} \otimes R_{Ipc}\} \tag{14}$$

where:

$R_{Ipf} = [p_f, p, q_f]$: Relationships between p and parent node;

$R_{Ipc} = \{[p, p_{cj}, q_{cj}]\}$: Set of relationships between p and children nodes;

p_f: Parent node of p;

q_{cj}: Assembly quantity of p and sub-node;

q_f: Assembly quantity of p and parent node.

4.4. Procedure of rule-based BOM multi-view mapping algorithm

EBOM view, PBOM view and MBOM view are foundation of BOM multi-view transformation process. Therefore, the article would illustrate mapping algorithm flow for them. The specific description is shown in Figure 4.

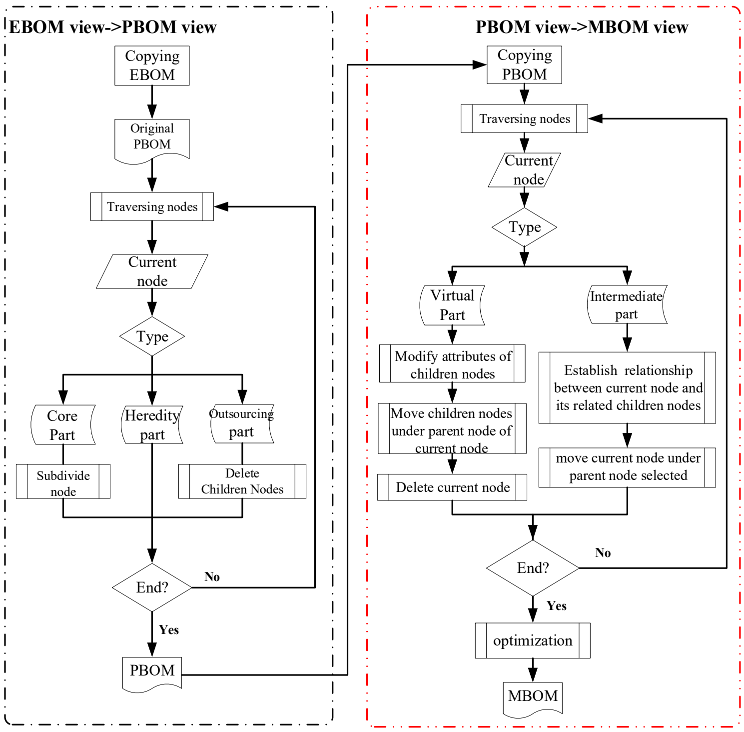

Figure 4. BOM multi-view mapping process.

When EBOM view is transformed to PBOM view, core parts, heredity parts and outsourcing parts would mainly be considered. The specific steps are described below:

Step1: With copying EBOM, the original PBOM is formed.

Step2: On this basis, original PBOM is traversed in a loop. During each loop, the type of BOM node is determined.

Step3: If BOM node was a core part, it would be subdivided; If node was a heredity part, it would not be skip directly; And if node was an outsourcing part, its children nodes would be deleted.

Step4: Through traversing all the nodes, EBOM view would be mapped to PBOM view.

Similarly, When PBOM view is transformed to MBOM view, virtual parts and intermediate parts would be focused. The detailed steps are as follows:

Step1: the original MBOM is formed by copying the PBOM.

Step2: original MBOM is traversed. In the traversal process, the type of BOM node is determined in each cycle as well.

Step3: If it was a virtual part, attributes of its children nodes would be modified, then these children nodes should be move under parent node of current node, moreover, current node would be deleted; If it was an intermediate part, corresponding parent node of current node should be set, and then relationship between current node and its related children nodes would be established, furthermore, intermediate part would be moved under parent node selected.

Step4: Until the loop ends, the preliminary PBOM view will be generated.

In addition, at the end of transformation process described above, the corresponding manual adjustment would be allowed to optimize BOM view.

5. Illustrate example

5.1. Application of the rule-based BOM multi-view mapping method

This section will elaborate application of rule-based BOM multi-view mapping method. In Figure 5, the English letter indicates the identification of parts, and the number represents assembly quantity.

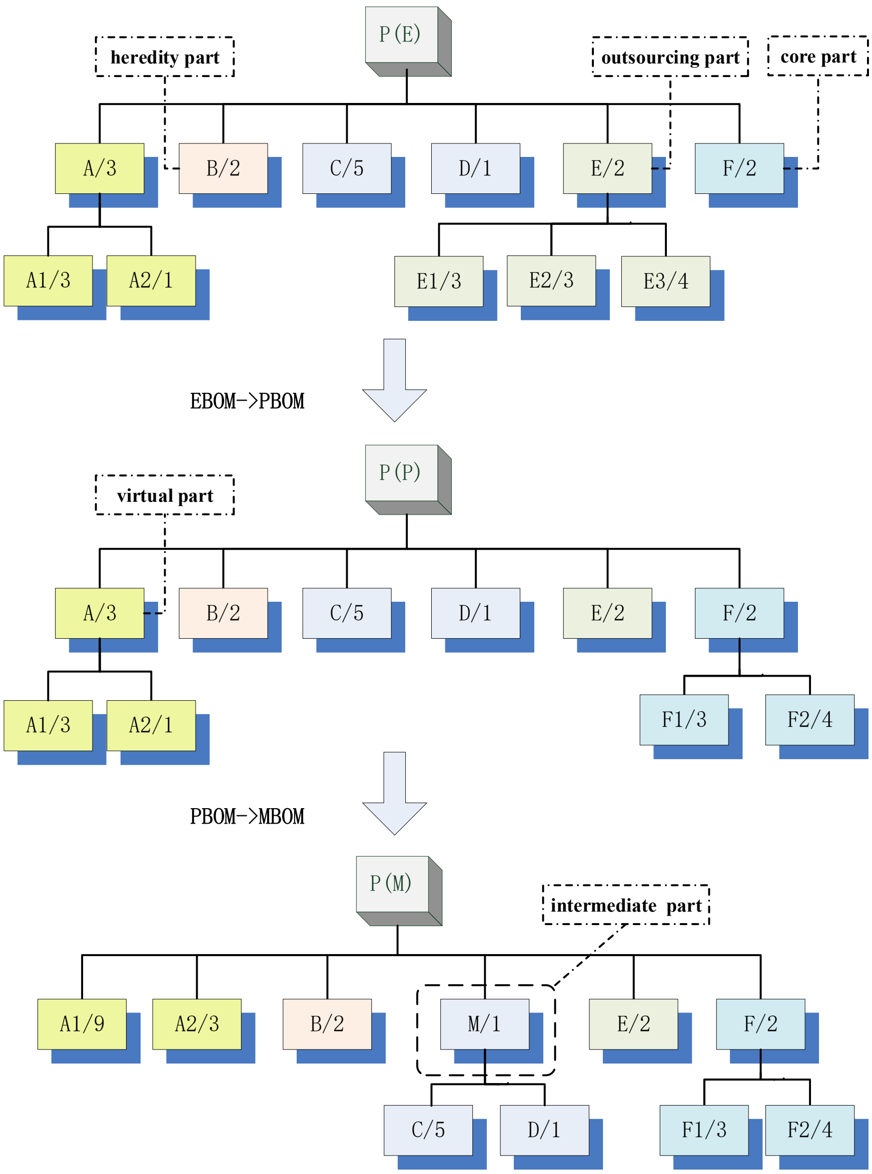

Figure 5. Example of BOM multi-view mapping method.

When EBOM view is transformed to PBOM view, core parts would be decomposed in detail by process engineers. Due not to considering process planning and manufacturing, outsourcing parts should be treated as a whole, whose sub-nodes would be shielded. Besides, heredity parts would be remained intact. Supposing F is core part in figure, the mapping process can be indicated as:

$$
\begin{aligned}
f_C(F) &= \{P^o + \{F_1, F_2\}, R^o{}_{Tr} + \{[F, F_1, 3],[F, F_2, 4]\}\} \\
&= \{\{P, A, A_1, A_2, B, C, D, E, E_1, E_2, E_3, F, F_1, F_2\}, \\
&\quad \{[P, A, 3],[P, B, 2],[P, C, 5],[P, D, 1],[P, E, 2],[P, F, 2], \\
&\quad [A, A_1, 3],[A, A_2, 1],[E, E_1, 3],[E, E_2, 3],[E, E_3, 4],[F, F_1, 3],[F, F_2, 4]\}\}
\end{aligned} \tag{15}
$$

Supposing E is outsourcing part in figure, the mapping process can be regarded as:

$$
\begin{aligned}
f_O(E) &= \{P^o - \{E_1, E_2, E_3\}, R^o{}_{Tr} - \{[E, E_1, 3],[E, E_2, 3],[E, E_3, 4]\}\} \\
&= \{\{P, A, A_1, A_2, B, C, D, E, F, F_1, F_2\}, \\
&\quad \{[P, A, 3],[P, B, 2],[P, C, 5],[P, D, 1],[P, E, 2], \\
&\quad [P, F, 2],[A, A_1, 3],[A, A_2, 1],[F, F_1, 3],[F, F_2, 4]\}\}
\end{aligned} \tag{16}
$$

If there were sub-nodes under child nodes, it would be necessary to delete them cyclically by subtraction operation. When PBOM view is transformed to MBOM view, virtual parts no longer appear, whose children parts are move under parent part. Meanwhile, the nodes of intermediate parts should be added, whose assembly relationship information would be supplemented. In addition, assembly quantity should also be maintained carefully. For instance, if the number of a certain virtual part is n, then, the number of sub-nodes of it must be expanded by n times in MBOM.

Supposing A is virtual part in figure, the mapping process can be represented as:

$$
\begin{aligned}
f_V(A) &= \{P^o - A, \overline{P, A} R^o{}_{Tr} + (3-1)\overline{P, A}\{[A, A_1, 3],[A, A_2, 1]\}\} \\
&= \{\{P, A_1, A_2, B, C, D, E, F, F_1, F_2\}, \overline{P, A}\{[P, A, 3],[P, B, 2], \\
&\quad [P, C, 5],[P, D, 1],[P, E, 2],[P, F, 2],[A, A_1, 3],[A, A_2, 1], \\
&\quad [F, F_1, 3],[F, F_2, 4]\} + 2\overline{P, A}\{[A, A_1, 3],[A, A_2, 1]\}\} \\
&= \{\{P, A_1, A_2, B, C, D, E, F, F_1, F_2\}, \{[P, B, 2],[P, C, 5],[P, D, 1], \\
&\quad [P, E, 2],[P, F, 2],[P, A_1, 3],[P, A_2, 1],[F, F_1, 3],[F, F_2, 4]\} + \\
&\quad \{[P, A_1, 6],[P, A_2, 2]\}\} \\
&= \{\{P, A_1, A_2, B, C, D, E, F, F_1, F_2\}, \{[P, A_1, 9],[P, A_2, 3],[P, B, 2], \\
&\quad [P, C, 5],[P, D, 1],[P, E, 2],[P, F, 2],[F, F_1, 3],[F, F_2, 4]\}\}
\end{aligned} \tag{17}
$$

Supposing M is intermediate part in figure, the mapping process can be implied as:

$$
\begin{aligned}
f_I(M) &= \{P^o + M, R^o{}_{Tr} + [P, M, 1] + \{[M, C, 5],[M, D, 1]\} - \\
&\quad [P, M, 1] \otimes \{[M, C, 5],[M, D, 1]\}\} \\
&= \{\{P, A_1, A_2, B, C, D, E, F, F_1, F_2\}, \{[P, A_1, 9],[P, A_2, 3],[P, B, 2], \\
&\quad [P, C, 5],[P, D, 1],[P, E, 2],[P, F, 2],[F, F_1, 3],[F, F_2, 4]\} + \\
&\quad [P, M, 1] + \{[M, C, 5],[M, D, 1]\} - \{[P, C, 5],[P, D, 1]\}\} \\
&= \{\{P, A_1, A_2, B, C, D, E, F, F_1, F_2\}, \{[P, A_1, 9],[P, A_2, 3],[P, B, 2], \\
&\quad [P, E, 2],[P, F, 2],[F, F_1, 3],[F, F_2, 4],[P, M, 1],[M, C, 5],[M, D, 1]\}\}
\end{aligned} \tag{18}
$$

The transformation between BOMs causes the corresponding product structure to alter and also makes the BOM view evolve accordingly. Eventually, the product structure is displayed in the corresponding BOM view by tree manner, as shown in Figure 6.

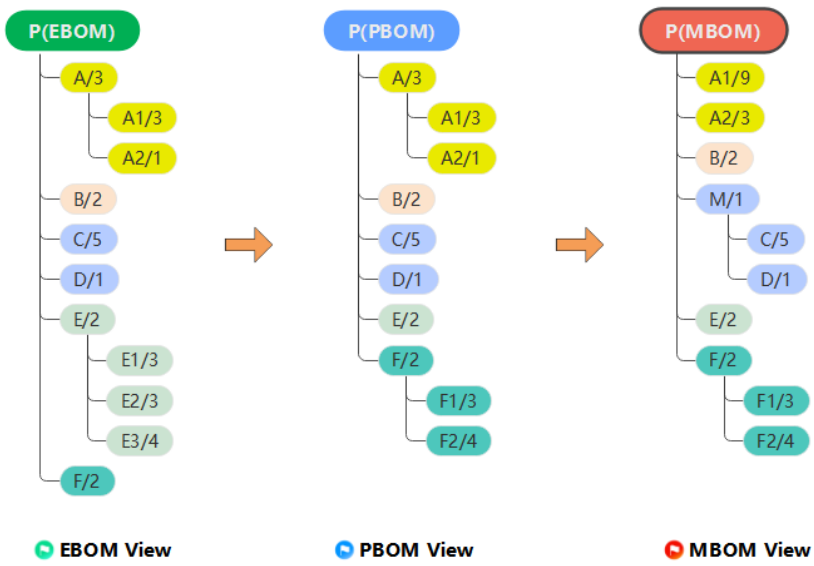

Figure 6. The diagram of the product structure by tree manner in BOM View.

5.2. The prototype of the BOM multi-view management

The prototype of the BOM multi-view management has also been developed. With linking to BOM node, prototype can support browsing, editing and modification for product structure in selected BOM view. Besides, it can display information about 2D/3D drawing as well as historical version records, etc. It’s convenient for engineers to implement work in BOM multi-view. Taking descaler product for the equipment manufacturing industry as an example, the main interfaces are performed in Figures 7–10.

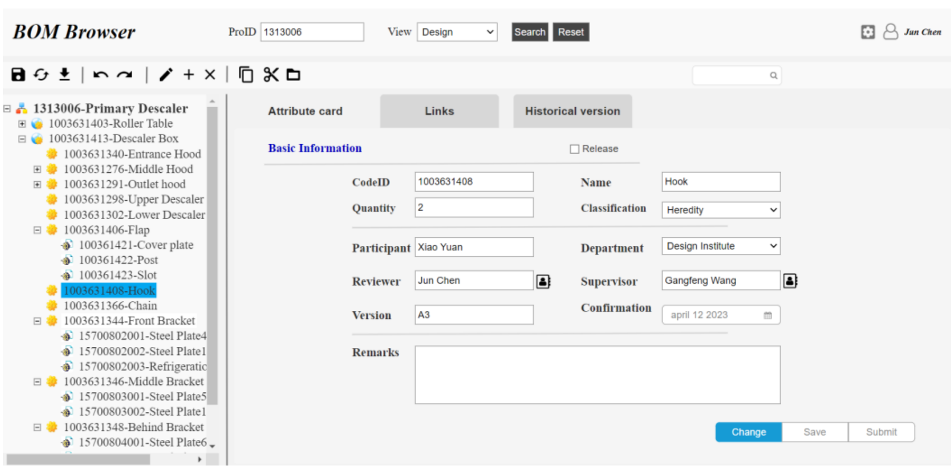

Figure 7. The main interface of the BOM multi-view management prototype.

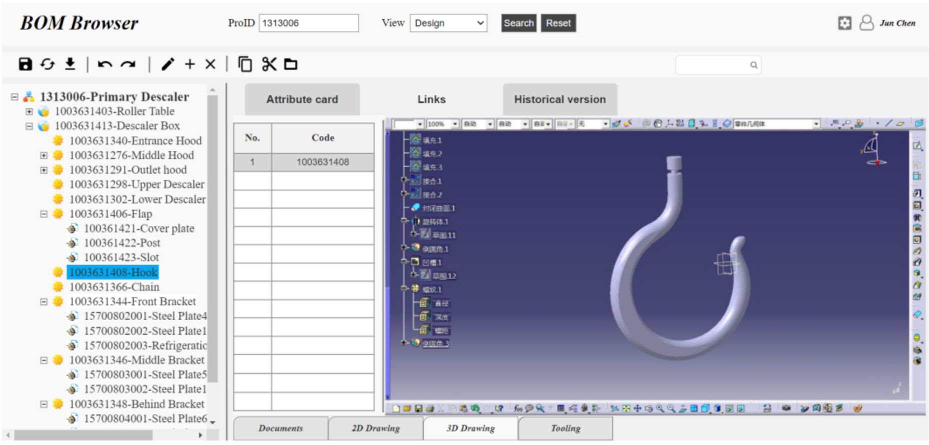

Figure 8. Application of links for BOM multi-view management.

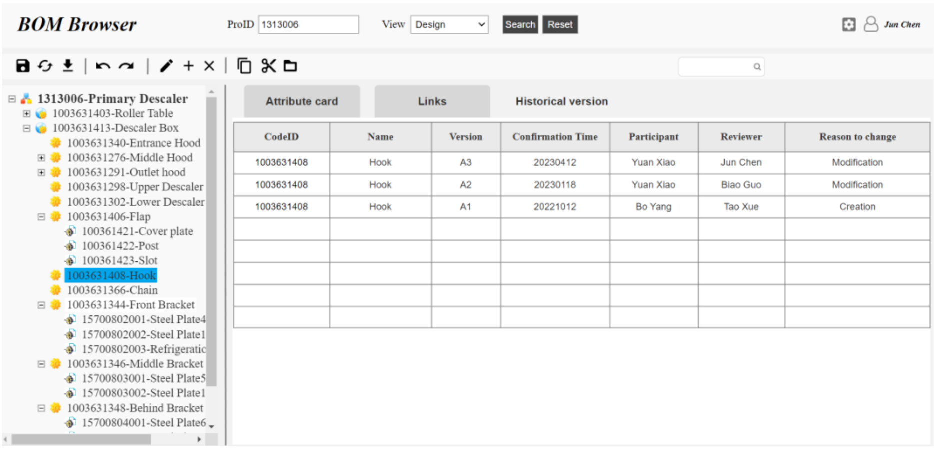

Figure 9. Application of versions for BOM multi-view management.

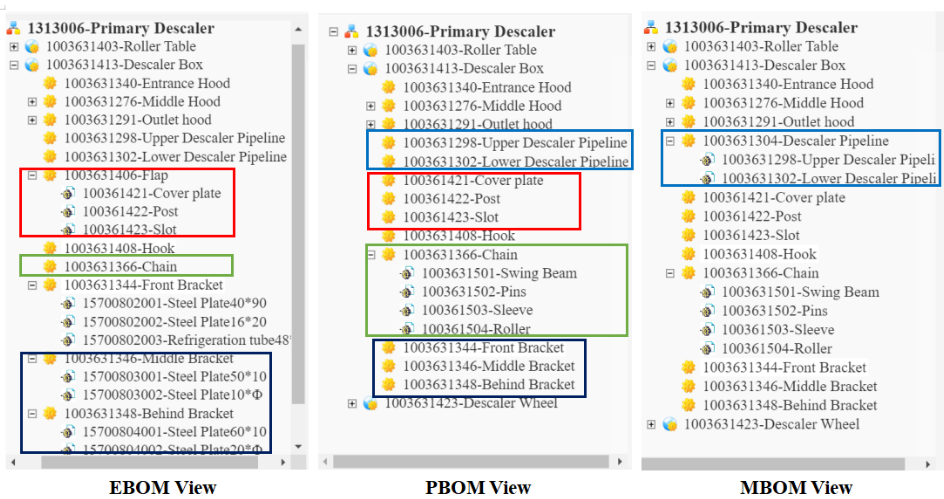

Figure 10. BOM multi-view of descaler box.

5.3. Discussion

BOM multi-view integrated management can present the product structure of each stage of product life cycle by various BOM views. With the product structure of corresponding view, each department can collaborate to manage and maintain BOM data as well as continuously improving product information, which enhances the completeness of BOM. Moreover, based on the BOM model of single data source, whether EBOM, PBOM, MBOM or XBOM, the source information is unified to ensure data consistency.

In the process of BOM multi-view transformation, compared with other methods, the proposed algorithm possesses the following advantages. First, the single data source is introduced to unify foundation data to ensure them not to be changed after transformation. If there was no unification, for example, the partID or part name could be changed (especially by manual), it would result in a situation where something the same is called by distinct titles and even disturb subsequent product development and data integration among information systems. Then, many methods focus on the conversion of EBOM to PBOM, while this method also considers the PBOM to MBOM. Finally, it achieves automatic transformation of BOM views by part classification and corresponding mapping rules, and also allows manual adjustment to optimize results, which can improve the efficiency of product development to a certain extent.

Currently, the prototype system focuses on equipment manufacturing industry as the entry point. In order to expand application to other industries such as energy, electronic semiconductors, medical [25] and so on, it’s still needed to make more industry research and development.

6. Conclusions and future work

With increasing complexity of modern products and the widespread utilizing of intelligent manufacturing technologies, the BOM types continue to expand and product data contained also keeps on growing rapidly. In order to satisfy with actual requirements of development and manufacturing, the diversity, accuracy and consistency characteristics of BOM in multi-view transformation process should be controlled and managed effectively, although these are extremely challenging for enterprises.

The paper constructs the BOM multi-view integrated management framework, which associates product data formed in various life cycles and scattered in distinct information systems. Through unified logical management and strict constraints, BOM data are organized into a logical single data entity to form a single data source. Furthermore, the BOM evolution model is proposed with analyzing BOM evolution process of complex products. Meanwhile, BOM multi-view was provided to control and manage them. These would not only better respond to SSPD management requirements, but also beneficially support correlation, transformation and management of BOM data at all stages of product life cycle.

Moreover, the rule-based BOM multi-view mapping method is proposed. Through mapping analysis, rule definition and mathematical modelling for special parts of BOM multi-view transformation, the complex mapping process and application are illustrated to ensure the diversity, accuracy and consistency of data in BOM multi-view transformation.

The model and method proposed in paper can provide BOM multi-view management for various types of BOMs, improve BOM multi-view transformation efficiency and quality in business process and fulfil BOM data management and maintenance requirements of complex product life cycles. Currently, this paper mainly focuses on the equipment manufacturing industry. In the future, the research will be expanded to other industries to promote its versatility including energy, electronic semiconductors, medical, etc. Besides, the theory and technology about digital twin will also be incorporated into the research, which could promote intelligibility so as to possess a wide range of application.

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Conflict of interest

The authors declare no conflict of interest in this paper.

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