Integration of bill of materials with unified bill of materials model for commercial aircraft design to manufacturing

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Integration of bill of materials with unified bill of materials model for commercial aircraft design to manufacturing

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Abstract

The commercial aircraft enterprise faces a major challenge in product data management as it deals with increasing product complexity and global manufacturing. As such, the effective bill of materials management throughout the product lifecycle is becoming much more important for the advanced competitiveness. This study proposed a unified bill of materials model based on single source of product data for commercial aircrafts. This study illustrated the details of the unified bill of materials model throughout the product lifecycle and presented the technology to support the integration of engineering bill of materials and manufacturing bill of materials with unified bill of materials model. A prototype system was implemented to verify the developed technology by taking into account real cases of a local commercial aircraft enterprise. It proved that the developed technology could substantially improve industrial competitive advantage.

Keywords

Commercial aircraft, bill of materials management, single source of product data, product data management, unified bill of materials model

Introduction

In the context of global manufacturing, managing heterogeneous and scattered information is a key issue for product lifecycle management (PLM). Through PLM, bill of materials (BOM) convey key product information that guides development at different stages of a product lifecycle (Luh et al., 2010). Thus, BOM management has become the hub of information integration throughout the product lifecycle.

Global manufacturing has resulted in an increasingly complex and multidisciplinary network of industrial partners, which spread globally and are bound by common business objectives. BOMs are stored, processed, and communicated in different ways by heterogeneous enterprise applications, which mainly depend on requirements of distributed teams. Hence, the BOM is required to be consistent across information systems.

On the one hand, the heterogeneity of BOMs, their domains, and their users could result in misunderstandings or loss of information in the BOMs throughout the entire lifecycle. On the other hand, because of the high complexity of commercial aircrafts, the design is usually evolutionary and dynamic, with the variable BOMs developed gradually in separate organizations of the different lifecycle phases. BOM is initially developed by the engineering department to meet engineering needs. Multiple departments would then reference the BOM and use the information it contains in different views. With the evolution of the product, BOMs likewise change in terms of their structures and attributes. The information islands of scattered BOMs

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increase the difficulty of guaranteeing the integrality, correctness, and conformability of product data.

Therefore, a systematic approach to BOM management is required to support integration, structuring, interrelation, and synchronization of multidisciplinary product data. This study begins with a status review of BOM management. Gap analysis is conducted in "State-of-the-art review" section. To fill the gap, a unified BOM model based on single source of product data (SSPD) is proposed in "Unified BOM model based on SSPD" section. The key technology to enable engineering BOM (EBOM) and manufacturing BOM (MBOM) integration is developed in "Integration of EBOM and MBOM" section. In "Illustrated application" section, a demonstration is developed by using real cases from a commercial aircraft enterprise in China. Finally, conclusion and future perspectives are given.

State-of-the-art review

Definition of BOM management

BOM provides a structure representation to specify the configuration to build a product, including the relationship between the final products, parts, or materials, as well as the quantities of the subordinative parts and materials required in each assembly (Ji et al., 2003). BOM is the foundation of information sharing and exchange among departments at different phases. Accordingly, multi-view BOMs come into being through their respective stages, such as EBOM, MBOM, and service BOM (SBOM). BOM management can be defined as providing all functionalities needed to handle BOM at different lifecycle phases, such as modeling, creating, updating, integrating, and optimizing BOM to maintain reliability and traceability. BOM management facilitates integration of product information in multi-view BOMs throughout the product lifecycle, so that it could eliminate redundancy of BOMs and ensure consistency and integrity of the product data.

Current status review

To satisfy the emerging business challenges of product data management (PDM) in the past decades, both academic and industrial researchers have conducted extensive research on BOM management. Many researchers focused on BOM management in high-variety production with generic bill of materials (GBOM) and generic bill-of-materials-and-operations (BOMO; Jiao et al., 2000; Romanowski and Nagi, 2002). Moreover, a relational database approach was proposed for multiproduct and multiprocess production systems (Aydin and Güngör, 2005). For make-to-order environment, a product structure model was proposed to support the flexibility of a PLM system (Ni et al., 2008).

With focus on collaborative management of product data throughout the entire product lifecycle, a unified product structure management model was proposed for enterprise business process integration (He et al., 2006). Janardanan et al. (2008) presented a Web-based product structure manager for collaborative product structure management. Ming et al. (2008) proposed a collaborative approach through process planning and manufacturing for effective collaboration. To integrate the evolution of product structures and outfitting information during ship design, an enterprise BOM was modeled (Lee et al., 2012).

Other approaches of information systems to facilitate BOM management have been explored. Oh et al. (2001) proposed a Unified Modeling Language (UML)-based mapping methodology for product structure exchange between heterogeneous computer-aided design (CAD) and PDM systems. A tree-structure storage model has been proposed for efficient BOM management in manufacturing resource planning (MRPII; Ji et al., 2003). Eynard et al. (2004) explored the advantages of using an object-oriented approach and UML diagrams to specify the product structure and workflows for PDM implementation. Lee et al. (2011) proposed digital manufacturing as the key tool for integrating data between PDM and enterprise resource planning (ERP). Several other integration frameworks and technologies have also been reported (Kim et al., 2006; Ming et al., 2005; Schuh et al., 2008; Srinivasan, 2011; Sudarsan et al., 2005).

The brief review of related literature revealed that the BOM could provide an excellent approach to PDM. However, previous research efforts have mainly focused on BOM management in high-variety production or certain activities in design, manufacturing, or production. Hence, only a few studies examined BOM management throughout the product lifecycle of a complex product, such as commercial aircrafts.

Required solution for BOM management

The intrinsic complexity of the product design and global manufacturing of a commercial aircraft creates a new challenge for BOM management across a complex network throughout the entire product lifecycle. With multiple systems implemented, information integration is required to bridge gaps among scattered multi-view BOMs. The need to integrate information, which allows partners to collaborate effectively in creating innovative products, has motivated a unified design and deployment for commercial aircraft BOM with a single source. New technology solutions imperatively call for the following issues:

- To provide an SSPD logically throughout the product lifecycle;

- To provide a unified BOM model that supports multi-view BOMs at any lifecycle stage;
- To provide traceability of engineering changes among multi-view BOMs to ensure consistent product data throughout the product lifecycle.

Unified BOM model based on SSPD

SSPD framework for commercial aircraft

The SSPD framework aims to develop a framework model in a relational database environment. The framework would allow streamlining of the BOM management of key business processes throughout the entire commercial aircraft lifecycle, including the following phases:

- *Conceptual studies*—the customer configures the product with the configuration library.
- *Design and engineering*—based on the customer configuration, the engineering information for the product is generated.
- *Manufacturing and assembly*—the designed product is manufactured and assembled.
- *First flight and certification*—through a flight test, the certified product is delivered to the customer.
- *Service and support*—the products are used, maintained, and serviced by customers or engineers.
- *Recycle*—when a product no longer satisfies an initial purchaser, the product could be disassembled, refurbished, reassembled, recycled, reused, or disposed.

As shown in Figure 1(a), the BOM information flow is closed throughout the product lifecycle. Forward information flows are directly used as inputs for streamlining the operations of the next phases, and feedback information is used as knowledge for the upstream phases (Jun et al., 2007). All information is stored in the data dictionary to allow the design process to evolve in global enterprise perspectives. The data dictionary provides conceptual centralization of design information relative to the enterprise, which could guarantee the SSPD (Prasad et al., 1993). The framework could be used to develop an integrated BOM management system based on a PLM system. It allows BOMs of commercial aircrafts to be managed in a way that differs from traditional enterprise information systems and with the following benefits:

- Closing the product lifecycle information loops allows feedback of product-related information from downstream BOM back to the upstream BOM to produce competitive and sustainable products.
- Single data source of commercial aircraft product guarantees integrality, correctness, and conformability of the data in BOMs.
- A single BOM could be configured into multi-view BOMs depending on the requirement of downstream users.

Unified BOM model

Based on the single database, a unified BOM model (Figure 1(b)) was developed to understand dynamic BOM evolution and control synchronization between multi-view BOMs. The unified BOM model, as a standard to ensure that a consensus process takes place among various key actors in the application domain, is made as a reference by each enterprise application within a commercial aircraft enterprise. It provides formal definitions of basic business objects involved in the commercial aircraft development process and specific relationships among them, such as document, engineering module, and manufacturing module. With the concept of view in the unified BOM model, the single BOM could be automatically configured into different views of BOM, including EBOM, MBOM, test-flight BOM (TBOM), SBOM, and recycle BOM (RBOM). The association in the unified BOM model provides a feasible approach for information change in a dynamic BOM, which could guarantee synchronization and consistency of multi-view BOMs.

- With the links between multi-view BOMs and single BOM, any change in the part of EBOM could propagate to downstream BOMs and require a new version of the associated part. It indicates that the information in BOMs is horizontally dynamic over the lifecycle.
- Based on the association between objects in one BOM view, for any parts to be changed, the unified BOM model could guide the navigation to descend to the child parts and obtain specific business objects to be changed in the same BOM view. This situation means that the BOM information is also vertically dynamic in a single lifecycle phase.

The key point in implementing a unified BOM model in BOM management is to establish the relationships among BOM views when transforming BOMs. With the design and manufacturing as the main stages of the product lifecycle, "Integration of EBOM and MBOM" section focuses on the integration of EBOM and MBOM.

Integration of EBOM and MBOM

EBOM reflects the assembly relation and quantity of product parts from the engineering point of view, and it could not be used directly in downstream workflow (Tursi et al., 2009). MBOM is used to reflect the

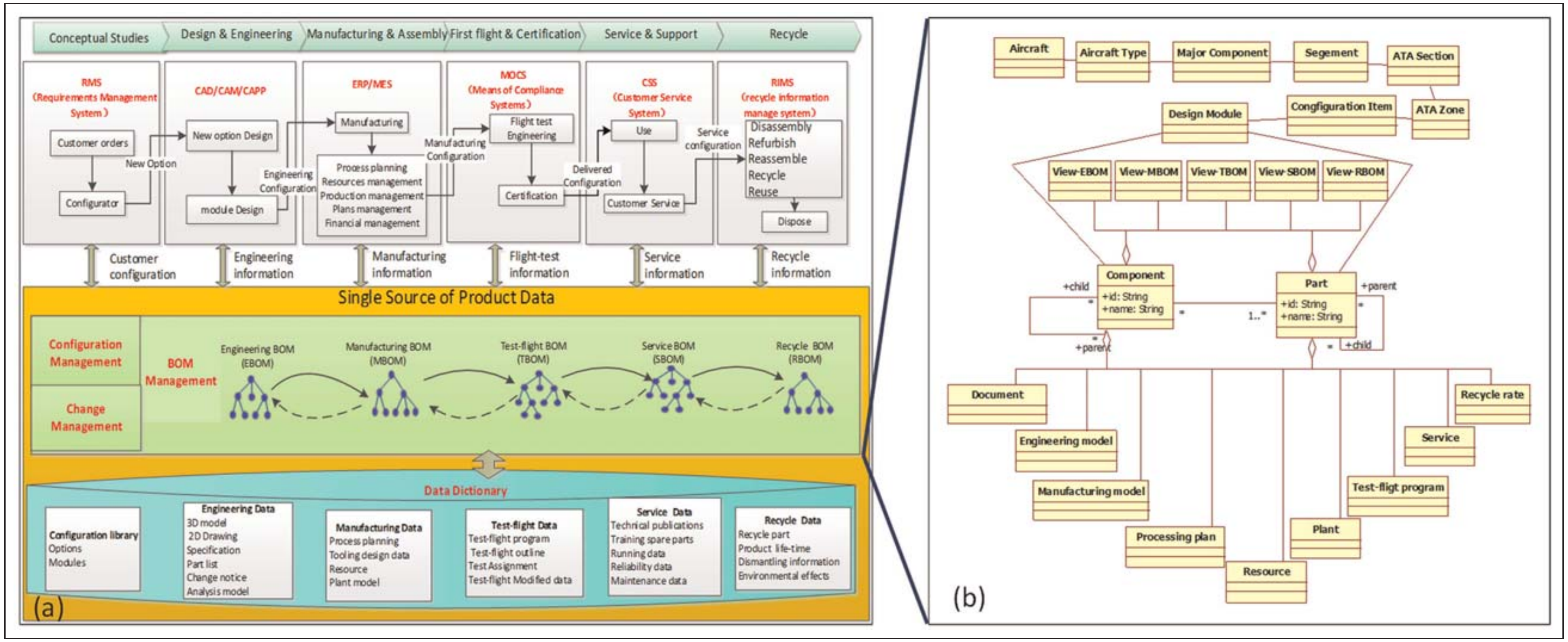

Figure 1. A unified BOM model based on SSPD: (a) SSPD framework for commercial aircraft product and (b) unified BOM model in UML.
BOM: bill of materials; SSPD: single source of product data; UML: Unified Modeling Language; CAD: computer-aided design; CAM: computer-aided manufacturing; CAPP: computer-aided process planning; ERP: enterprise resource planning; MES: manufacturing execution system.

product's manufacturing process, including manufacturing product structure (MPS) and process information. As shown in Figure 2(a), the process of integration between EBOM and MBOM consists of two aspects:

- *BOM structure transformation*—MPS is established by adjusting EBOM to the manufacturing and assembly process.
- *Process information integration*—process information (including process plan, resources, and plant layout) is linked to the relevant part in the MPS to reflect the material flow through the production process.

BOM structure transformation

Structure transformation aims to establish the relationship among parts in different BOMs. A mapping model was set up based on part classification and mapping rules to automatically realize structure transformation from EBOM to MPS.

Part classification. With collaborative manufacturing in commercial aircraft enterprises, integrated product teams adopted the DFx Technology (Zhang et al., 2004). Thus, the majority of parts that exist in MPS and EBOM have the same information; these parts are also known as inherited parts. However, the parts of the two structures differ in some ways, including the key part, out-assistant part, process part, and phantom part.

- *Inherited part*—this is the part that has the same information in EBOM and MPS.
- *Key part*—considering the separation surface of process and other reasons, if the decomposition of parts in EBOM is too rough, key parts require further division into key subparts in the MPS to refine the structure.
- *Out-assistant part*—it appears in both EBOM and MPS, but its subparts appear only in EBOM with the production type of outsourced processing.
- *Process part*—it is present in MPS and not in EBOM. Due to process requirements, it should also be stored in actual production after manufacturing.
- *Phantom part*—it is a reference to a set of parts in EBOM. The referenced parts are specified at the definition of the phantom part and organized as child parts of the phantom part. The phantom part does not physically exist, which means that it would not be manufactured nor stored in actual production. It is merely considered as a part of EBOM that assists in product design. Thus, no phantom parts are present in MPS but could be present in the EBOM to assist in product design.

Figure 2(b) shows how the parts of five categories can be dealt with to transform EBOM into MPS. No difference exists between the inherited parts (D) of EBOM and MPS; child parts of the key part (A) are inserted into MPS by a technologist; and subparts of out-assistant part (B) need to be deleted in MPS. While processing the process part (C), a new node is added to MPS, and the relevant parts in EBOM are inserted into MPS as its child parts. The phantom part (E) needs to be deleted in MPS. The child parts (E1, E2), which inherited the attributes of phantom part (E), are inserted in MPS to replace the phantom part (E).

BOM structure representation. The BOM structure tree consists of the parts and assembly relationships. This section introduces the basic definition to represent the BOM structure.

Definition 1. p refers to a part in the BOM structure, P refers to the set of all parts in the BOM structure, and r is a group of the three elements, which represents the assembly relationship of parts

$$r = (p_1, p_2, q), \quad p_1 \in P, p_2 \in P \tag{1}$$

If $q > 0$, a parent–child relationship exists between p_1 and p_2, and the assembly quantity is q; if $q = 0$, a parent–child relationship does not exist between p_1 and p_2, then $r = (p_1, p_2, 0) = \varnothing$, $\varnothing$ is an empty group; if $q < 0$, a child–parent relationship exists between p_1 and p_2, and the assembly quantity is $-q$; and if $p_1 = p_2$, $r = (p_1, p_2, q) = \varnothing$. The following assumptions are made: $(p_1, p_2, q) = (p_2, p_1, -q)$; $|(p_1, p_2, q)| = |(p_1, p_2, -q)| = q$. Three kinds of operational rules are given for r.

- Plus–minus operation

$$(p_1, p_2, x) \pm (p_1, p_2, y) = (p_1, p_2, x \pm y) \tag{2}$$

$$(p_1, p_2, x) \pm \varnothing = (p_1, p_2, x) \tag{3}$$

$$(p_1, p_2, x) \pm (p_3, p_4, y) = \{(p_1, p_2, x), (p_3, p_4, \pm y)\} \tag{4}$$

- Multiplication operation

$$k \cdot (p_1, p_2, x) = (p_1, p_2, kx) \tag{5}$$

- Replacement operation

$$\overleftrightarrow{f, p_1}(p_1, p_2, x) = (f, p_2, x), \quad p_1 \in P, p_2 \in P, f \in P \tag{6}$$

$$\overleftrightarrow{f, p_2}(p_1, p_2, x) = (p_1, f, x), \quad p_1 \in P, p_2 \in P, f \in P \tag{7}$$

The order of the three operations is arranged according to priority (highest to lowest) as follows: replacement

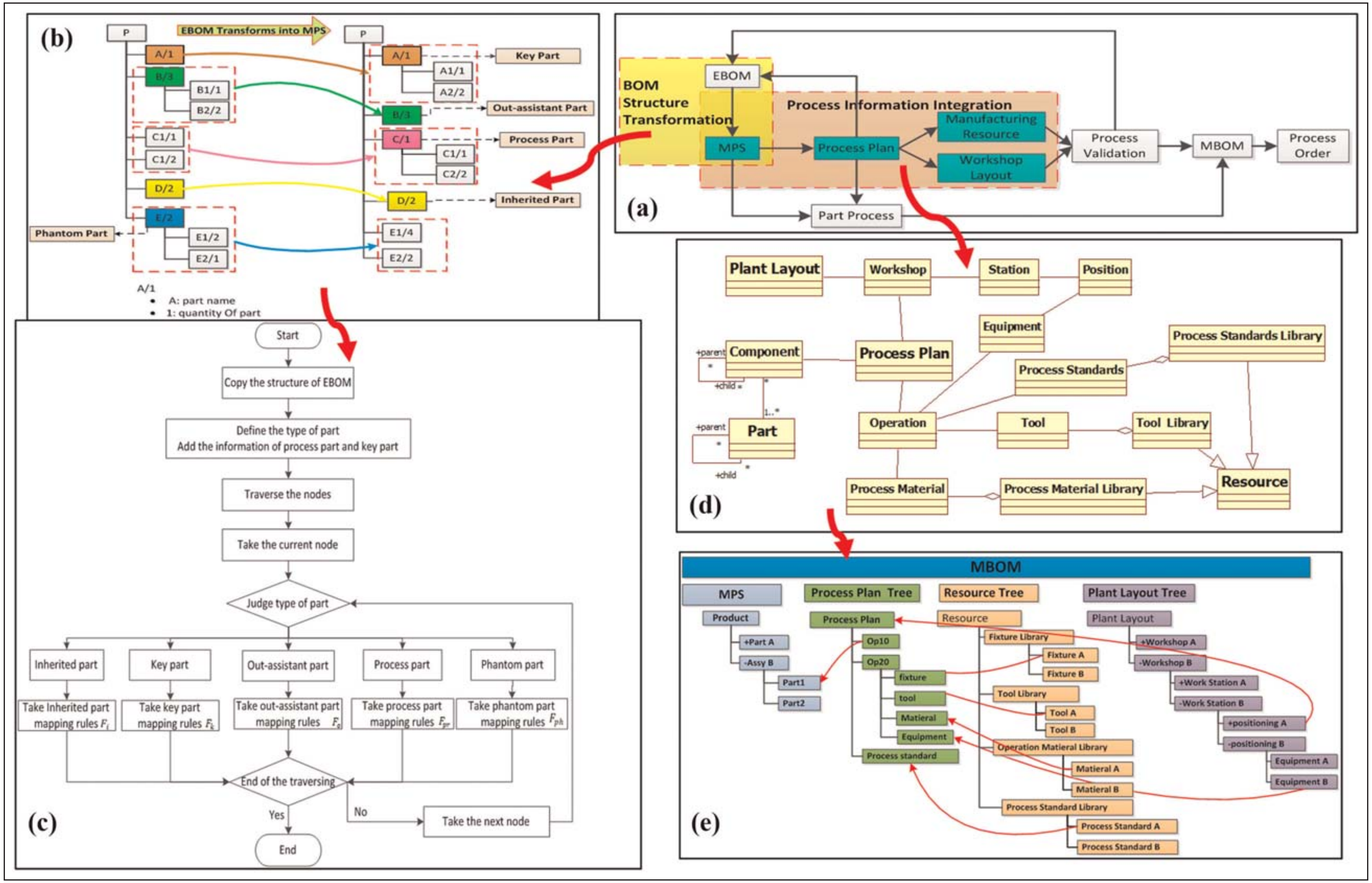

Figure 2. Integration of EBOM with MBOM: (a) the process of integration between EBOM and MBOM, (b) BOM structure transformation of EBOM to MPS, (c) the mapping between EBOM and MPS, (d) the UML class diagram for MBOM, and (e) the schematic view for MBOM.
BOM: bill of materials; EBOM: engineering BOM; MBOM: manufacturing BOM; MPS: manufacturing product structure; UML: Unified Modeling Language.

operation, multiplication operation, and plus–minus operation.

Definition 2. R represents the set of assembly relationship r for the part p

$$R(p) = \{r_1, r_2, \ldots, r_n\} \tag{8}$$

Only one child–parent assembly relationship exists in $R(p)$. Two operations exist for R:

- Δ operation: the goal of Δ operation on $R(p)$ is to obtain the father part of the part p. As shown in Figure 2(b), $\Delta R(B)_{EBOM} = P$.
- $||$ operation: the goal of $||$ operation on $R(p)$ is to obtain the assembly quantity in the assembly relationship for part p and its father part. In Figure 2(b), $|R(B)_{EBOM}| = 3$.
- *Definition 3.* S represents the set of R for the product

$$S = \{R(p_1), R(p_2), \ldots, R(p_n)\} \tag{9}$$

The BOM structure is used to represent the assembly relationship among the parts for the product and could be expressed by using the definitions above.

BOM structure transformation algorithm. According to the structural differences of the parts (inherited, key, out-assistant, process, and phantom) between EBOM and MPS, five mapping rules were proposed. P_I, P_k, P_o, P_{pr}, and P_{ph} are the relevant sets for the parts of five categories.

- Inherited part mapping rules F_i

$$\forall p \in P_I, \quad R(p)_{MPS} = R(p)_{EBOM} \tag{10}$$

- Key part mapping rules F_k

$$\forall p \in P_k, \quad R(p)_{MPS} = R(p)_{EBOM} + \sum_{1=1}^{1=n} (p, p_i, k_i) \tag{11}$$

In equation (11), p_i and k_i were provided by the designer, where p_i is the key subpart for key part and k_i is the assembly quantity in the assembly relationship for parts p and p_i.

- Out-assistant part mapping rules F_o

$$\forall p \in P_o, \quad R(p)_{MPS} = \left|R(p)_{EBOM}\right| \cdot \left(p, \Delta R(p)_{EBOM}, -1\right) \tag{12}$$

- Process part mapping rules F_{pr}: $\forall p \in P_{pr}$

$$\begin{cases} R(p)_{MPS} = \left(p, \Delta R(p_1)_{EBOM}, -k\right) + k \cdot \left(\sum_{1=1}^{1=n} \left(p, p_i, \frac{|R(p_i)_{EBOM}|}{k}\right)\right) \\ R\left(\Delta R(p)_{MPS}\right)_{MPS} = R\left(\Delta R(p)_{MPS}\right)_{EBOM} + R(p)_{MPS} - k \cdot \overleftrightarrow{\Delta R(p)_{MPS}, p} \; R(p)_{MPS} \end{cases} \tag{13}$$

In equation (13), k is the assembly quantity of the process part in MPS, where p_i is the process subpart of the process part, which appears in EBOM and $\Delta R(p_1)_{EBOM}$ is the parent part of the process subpart in EBOM.

- Phantom part mapping rules F_{ph}

$$\begin{aligned} \forall p \in P_{ph}, \quad & R\left(\Delta R(p)_{EBOM}\right)_{MPS} \\ = & \; \overleftrightarrow{\Delta R(p)_{EBOM}, p} \; R\left(\Delta R(p)_{EBOM}\right)_{EBOM} \\ & + \left|R(p)_{EBOM}\right| \cdot \overleftrightarrow{\Delta R(p)_{EBOM}, p} \; R(p)_{EBOM} \end{aligned} \tag{14}$$

With the mapping rules above, the mapping algorithm from EBOM to MPS could be expressed by using equation (15) as shown below

$$S_{MPS} = F_{ph}\left(F_{pr}\left(F_o\left(F_k\left(F_i\left(S_{EBOM}\right)\right)\right)\right)\right) \tag{15}$$

Mapping between EBOM and MPS. Figure 2(c) illustrates the flow path of structure transformation from EBOM to MPS. In generating new parts when processing key and process parts, the structure transformation needs human–computer interaction. Structure transformation from EBOM to MPS presented a BOM transformation method based on feature identification, which keeps the data among BOM views integral, accurate, and consistent.

Process information integration

During the manufacturing phase, MBOM could be supplemented by specifying the sequence of processes required to obtain the product, as well as the materials, resources, and work centers needed at each operation. The installation and manufacturing part in MBOM are linked with the process information. The process information integrated with MBOM could be categorized into the following objects:

- *Process plan data*—this defines the sequence of activities to fabricate each part and assemble each component, including assembly process, parts manufacturing process, tooling order, and testing basis.
- *Resource data*—this describes the resources required for each process, including tools, fixtures, process material, and process standards.
- *Plant layout data*—this describes the factory production line, including the workshop, station,

position, and equipment. If arranged in these positions, the equipment cannot be used for any other purpose.

The UML class diagram and schematic view for MBOM are shown in Figure 2(d) and (e), respectively. Specific association links exist between MPS and process information. The integration of MPS, process tree, resource tree, and plant tree reflects the material flow through the production process.

Illustrated application

Prototype system architecture

The proposed unified BOM model based on SSPD was implemented with a relatively simple product in a commercial aircraft enterprise in China. The Web-based prototype system and enterprise configuration management system (ECMS) were developed. PTC's Windchill was selected as the development platform in ECMS because it is designed to enable complex management of the configurations of sophisticated products. In addition, Windchill is a platform that is used to control, cooperate, and communicate information about the product (Deszczyński, 2012). With the integration tool Info*Engine provided by Windchill, ECMS and other enterprise applications were integrated to ensure that a single source of information would be obtained. Figure 3 shows the Web architecture of the prototype ECMS.

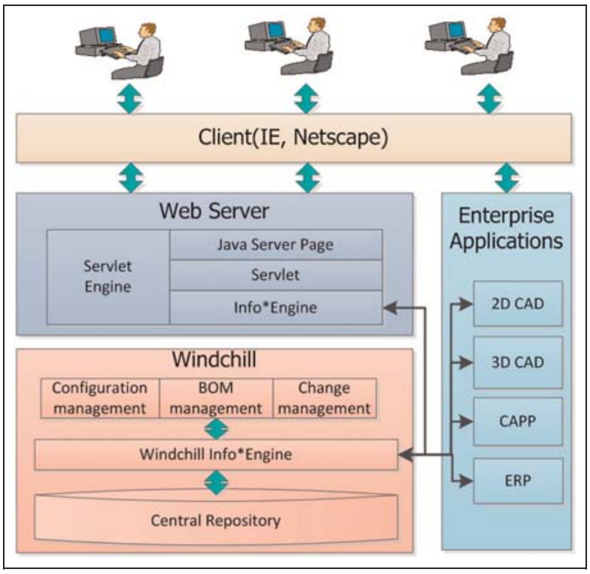

Figure 3. System architecture of the prototype system ECMS. BOM: bill of materials; CAD: computer-aided design; CAPP: computer-aided process planning; ERP: enterprise resource planning; ECMS: enterprise configuration management system.

Application of unified BOM model

The unified BOM model in ECMS is applied as follows:

Step 1. The connectivity between the product data is analyzed, and appropriate relations are proposed.
Step 2. The unified BOM model is formulated with the connectivity proposed in Step 1, and the structure transformation algorithm proposed in "BOM structure transformation algorithm" section is formulated.
Step 3. Product data are input into the system, and the part type is defined.
Step 4. The mapping algorithm is used to conduct the structure transformation from EBOM to MPS.
Step 5. The process information for the object in MPS is formulated, and the MBOM is generated.

The BOM information management of the horizontal tail for commercial aircraft was used as an example to specify the function of the prototype system. To illustrate clearly, the horizontal tail structure in the study has been simplified. The processes consist of EBOM design, BOM structure transformation, and process information integration. Figure 4 presents user interfaces of the BOM structure transformation. As shown in Figure 4(a), the designer constructs the EBOM in the user interface named *EBOM Explore*. On the right-hand side of the user interface, the tabs named *Where Used*, *Uses*, *Documentation*, and *Information* are provided. For each part in EBOM, the designer can use these tabs to edit the child part, parent part, related documentation, and the essential information, respectively. With the tabs *Information* and *Object Attributes*, the part type is defined in this step (Figure 4(b)). In the EBOM of the horizontal tail, the component center box is the out-assistant part, the part trailing edge tank is the key part, the component elevator control system is the phantom part, and the rest of the parts and components are the inherited parts. In Figure 4(c), EBOM is opened in the user interface named *MPS Explorer*, and the process part and subparts for the key part are added in EBOM. For horizontal tail, component outboard (outbd) box is the process part, and the stiffening rib and outbd rear spar are subparts of the key part (trailing edge tank). With the design information defined, the next task is BOM structure transformation. As shown in Figure 4(d), the *View Name* and *BOM Type* are defined in the user interface named *BOM View Transformation*. Based on the hierarchical structure of EBOM and considering the type of each part, the MPS is created when clicking the "*OK*" button (Figure 4(e)). The relationship between EBOM and MPS has been

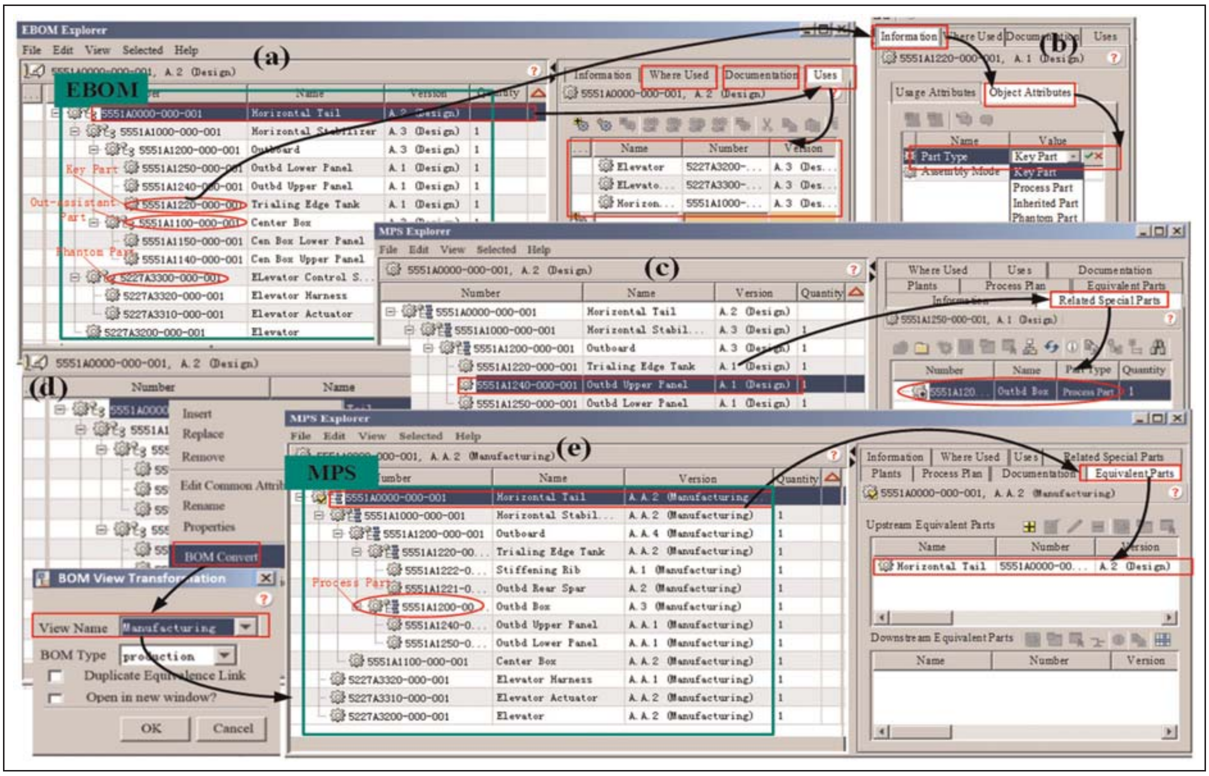

Figure 4. BOM structure transformation in ECMS: (a) EBOM, (b) part type, (c) related special part, (d) BOM transformation, and (e) MPS.
BOM: bill of materials; EBOM: engineering BOM; MPS: manufacturing product structure; ECMS: enterprise configuration management system.

established with the BOM structure transformation. With the tab named *Equivalent Parts* on the right-hand side of the *MPS Explorer*, the designer could search the upstream equivalent part in EBOM for the related part in MPS.

The process information integration is illustrated in Figure 5. In the user interfaces named *Manufacturing Resource Explorer*, *Plant Explorer*, and *Process Plan Explorer*, the designer constructs the resource, plant layout, and process plan trees, respectively. On the right-hand side of the user interface *Process Plan Explorer*, the tabs named *Resource Allocations*, *Plants*, and *Part Allocations* are provided (Figure 5(d)). With these tabs, the related part in MPS, the manufacturing resource, and the plant are assigned for the process plan to reflect the material flow through the horizontal tail assembly process. With the established relationships among MPS, manufacturing resource, plant, and process plan, the process information and MPS are integrated as MBOM.

Through BOM structure transformation and process information integration, EBOM and MBOM were integrated. Thus, the prototype system could guarantee product data evolution from EBOM to MBOM. Meanwhile, the relationship among objects in BOMs allows tracing back and forth key part and information. For instance, if changes occurred on MPS, the related upstream equivalent part in EBOM, process plan, manufacturing resource, and plant could be tracked and managed effectively with relative tabs in the user interfaces (Figures 4(e) and 5(d)).

Advantage analysis

Various BOM management approaches and information integration methods were mentioned in "Current status review" section. The advantages of the proposed model over the approaches presented in other studies are as follows:

- With the BOM view and relationship in the unified BOM model, the BOMs in different lifecycles were integrated into a single BOM, and product data evolution and traceability were guaranteed. The integrated information enabled effective collaboration. The relationship among BOM objects provides an effective way to handle change propagation. Therefore, the cost and number of engineering changes could be reduced.

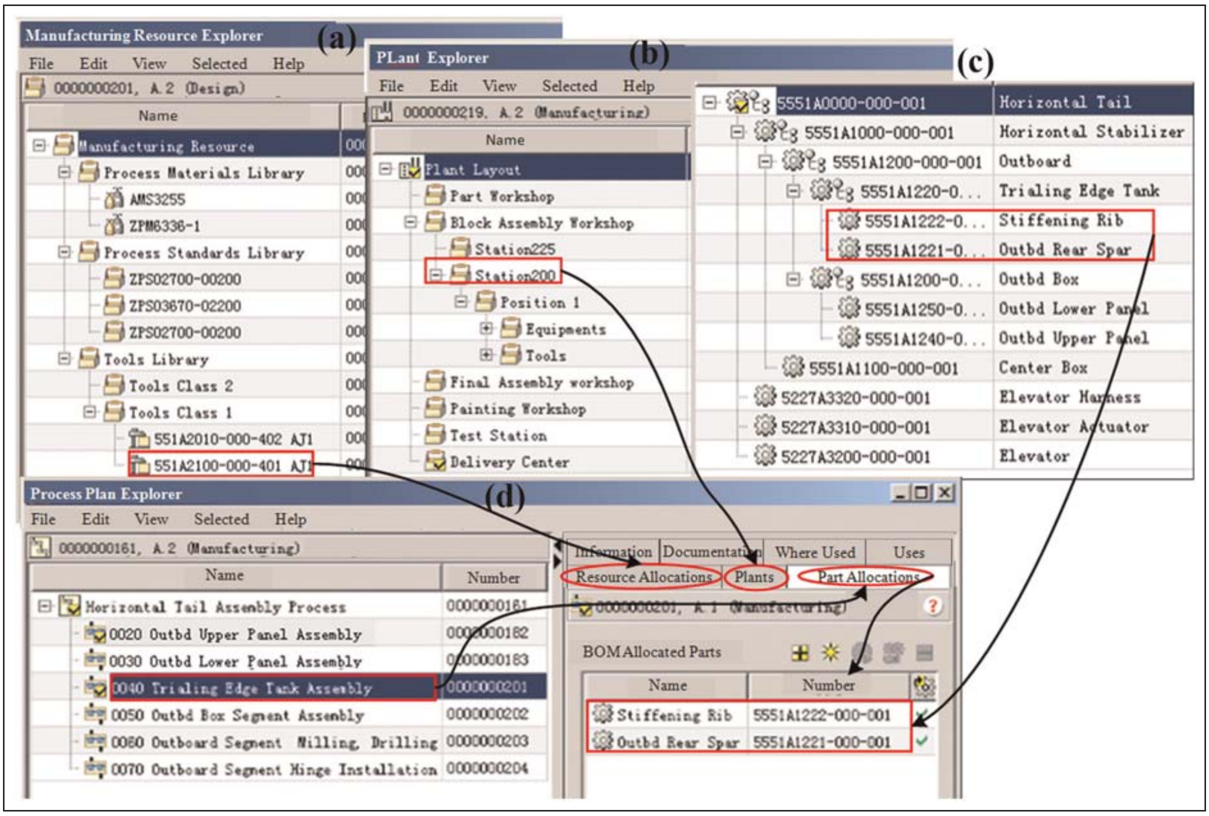

Figure 5. Process information integration in ECMS: (a) resource tree, (b) plan layout tree, (c) MPS, and (d) process plan tree. ECMS: enterprise configuration management system; MPS: manufacturing product structure.

Table 1. Improvements in deploying the prototype system.

Areas	Before implementation	After implementation	Improvement
Reduction of cycle time in product design (day)	17	13–14	17%–24%
Reduction of cycle time in MPS establishment (day)	4	2.5	37.5%
Reduction of cycle time in planning and scheduling (day)	5	3.5–4	25%–30%
Reduction of cycle time in change processing (day)	1–2	0.5–1	~50%
Reduction of engineering change number for product	39	27	~30%

MPS: manufacturing product structure.

- In terms of part classification and mapping rules, automatic BOM structure transformation based on feature identification was simple and easy to implement. Hence, increased work efficiency was observed.
- The manufacturing information in the four trees was integrated into MBOM to reflect the material flow throughout the production process. The integrated MBOM links various types of information systematically and provides an effective way for engineers to rapidly acquire the process information for a part in real time. Thus, planning and scheduling times were reduced.

An analysis of major improvements in the commercial aircraft enterprise was conducted based on data collected over a period of 10 months for a typical product with about 150 standard, custom, and developed components. The product was compared with a similar product before system implementation. Table 1 shows a summary of the major achievements of the analysis. With comprehensive integration and streamlined access to BOM information, major achievements in the commercial aircraft enterprise include reduced cycle time in product design, MPS establishment, planning and scheduling, and reduced engineering changes.

However, BOM management is highly complex and requires proper tools and knowledge in each corresponding stage. Thus, workflow management, change management, new standards for trust, and security of shared product information should be employed to refine the capability of unified BOM model as a comprehensive solution for BOM management.

Conclusion

The study proposed a unified BOM model for commercial aircraft design to manufacturing integration to ensure that the BOM could be effectively managed throughout the entire product lifecycle. The study was motivated by the need for an effective way to manage BOM, complex data integration issues, and maintenance when multiple systems were implemented in global manufacturing of a commercial aircraft enterprise. With the proposed unified BOM model, BOM was integrated and could be accessed and updated by different people from various disciplines in the right format according to their requirements throughout the entire product lifecycle. A prototype system has been deployed for a commercial aircraft enterprise in China. The proposed model and prototype system ensure effective BOM management to allow a commercial aircraft manufacturing company to achieve significant improvements. Future research should focus on the technology to support the integration of EBOM and SBOM.

Declaration of conflicting interests

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