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PRODUCT STRUCTURE RELATION BASED CONFORMITY INSPECTION FOR CIVIL AIRCRAFT

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ABSTRACT

Civil aircraft is a kind of complicated product with the tremendous product data and intricate data evolution process. Data consistency management in the product lifecycle is an extremely significant problem especially for the civil aircraft product. Product data consistency management for civil aircraft is not only required by the airworthiness certification on product conformity inspection, also related to the success of the new product development. On the product data consistency management, there are many researches which focus and discuss on the structure of BOM data, BOM data maintenance method, but few study on the technique of multi-BOM data consistency inspection method. In this paper, the aircraft product BOM layer and structure are analyzed in the "airframer-suppliers" development model, operations and changes during the BOM transition and reconstruction from engineering BOM to manufacturing BOM are illustrated. The differences between engineering BOM and manufacturing BOM which are generated during the BOM transition are classified into “normal inconsistencies” and “erroneous inconsistencies”. For the erroneous inconsistencies inspection, a product structure relation based conformity inspection method is proposed. The corresponding algorithm is clarified, and its workflow is described in detail. The civil aircraft conformity inspection system is developed. The method and system are applied in practical product data management of ARJ21-700 and verified efficiently.

Keywords: *Product Data Management, Data Conformity Inspection, BOM, Conformity Inspection Algorithm*

1. INTRODUCTION

The design and manufacturing of civil aircraft product is a long-cycle and high risk system engineering. Developing a new type of aircraft from design to production generally takes at least 24 months [1]-[3]. The first aircraft of ARJ21-700 took about 80 months from the development project beginning to the start of production. With the cooperation between enterprises in depth, the design and manufacturing data will be produced and reconstituted in different collaboration units. The consistency of product data in the lifecycle is a serious problem especially to the complex aircraft products. At the same time, civil aircraft as a special product, its’ safety requirement is very high. Manufacturer must obtain the airworthiness certification before delivering the product to the customer. The airworthiness certification process involves the product data conformity inspection. Therefor the effective consistency inspection method and the corresponding tools to support aircraft product data consistency management are critical.

2. SUMMARY OF RELATED WORK

The BOM data is the most basic, universal and common means of product data. The researches of product data consistency management are mostly based on BOM structural data [4], [5]. There are much more research works on the data consistency maintenance method and tools for the multi-BOM, but fewer study works on the conformity inspection method and tools for product data. The discussions of data consistency inspection algorithm are mostly

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described in isomorphism problem based on the graph theory and matrix theory. The product is decomposed into many small parts, and then data consistency inspection is carried out with each small part. These methods are usable for products simply in structure. But to the complex products, the scale of the civil aircraft product matrix is too large to calculate, and it is very time-consuming [6]-[10].

Based on the above contents, the rest of paper is organized as follow. In Section 3 we analyse the product data structure, the changes made during the transition from engineering BOM to manufacturing BOM and the difference and inconsistency problem in the product data evolution. And relation based data consistency inspection method and corresponding algorithm are presented in Section 4. The system tools and its application in practice are explored in the Section 5. We conclude our paper and suggest some possible future direction in Section 6.

3. ANALYSIS OF TRANSITION FROM ENGINEERING BOM TO MANUFACTURING BOM

3.1 EBOM, M-BOM, SPSBOM and SBOM

The manufacture of civil aircraft usually takes the "airframer-suppliers" business model. In the development of a new type craft, there will be many suppliers who have close cooperation with final assembly plant to provide aircraft subassembly parts. Each participant will build its BOM for its production based on the design requirements. The following will give the definition and description of all the BOM type.

(1)EBOM

EBOM is generated late in the design stage. It is formed according to the work of engineering designer in accordance with the customer orders and the product functional requirement [11]-[13]. The typical EBOM of aircraft are described in the Figure1. In the product lifecycle, EBOM is following BOM’s input data, and it will be converted to the manufacturing BOM. And the product consistency inspection is based on it.

(2) Airframer’s manufacturing BOM (M-BOM)

EBOM reflect the product design structure, M-BOM in this paper refers to the airframer’s manufacturing BOM. It generate from the EBOM after the transition by the process engineer in consideration of manufacturability and assemblability [14]-[18]. The typical M-BOM of aircraft are described in the Figure1. Top layer of the M-BOM is the work station and position station divided from the aircraft’s general assembly process, the middle layer includes the assembly outline and its process assembly parts, engineering assembly parts and the subassembly parts provided by the suppliers. The scattered parts provided by the supplies in the workpiece package are also listed in the M-BOM. The bottom layer includes the components and the parts.

(3) Supplier product standard BOM (SPSBOM)

SPSBOM is set up by the airfraimer which is the product BOM requirement collection of the subassemblies provided by the suppliers. It has main three layers, the top layer is the product type and the suppliers, the middle layer is the product packages by the suppliers, and the bottom layer includes the component parts and scattered parts.

(4)Supplier BOM (SBOM)

SBOM is defined as the subassemblies’ BOM structure which will be finally delivered by the suppliers. It records the product data information during the manufacturing period in the suppliers’ plants and the information in it should be accordant with real physical subassembly product. It is provided by the supplies and accompany with the product delivery.

The M-BOM is the main airframer’s basic BOM which is transformed from EBOM. SPSBOM is established by the main airframer according to the EBOM and M-BOM as the product delivery standards of suppliers’ subassemblies. And SBOM is the material information of the eventual physical subassembly product. Therefore the relations between BOMs mentioned above are complicated which is showed in the Figure 1.

3.2 BOM Reconstruction Operation and Difference Analysis

In the product design process, the engineering BOM is formed according to the function and subject. The “top-down” methodology is usually adopted to set up the product engineering BOM and finish the detail design. But on the contrary, the manufacturing BOM is formed according to the

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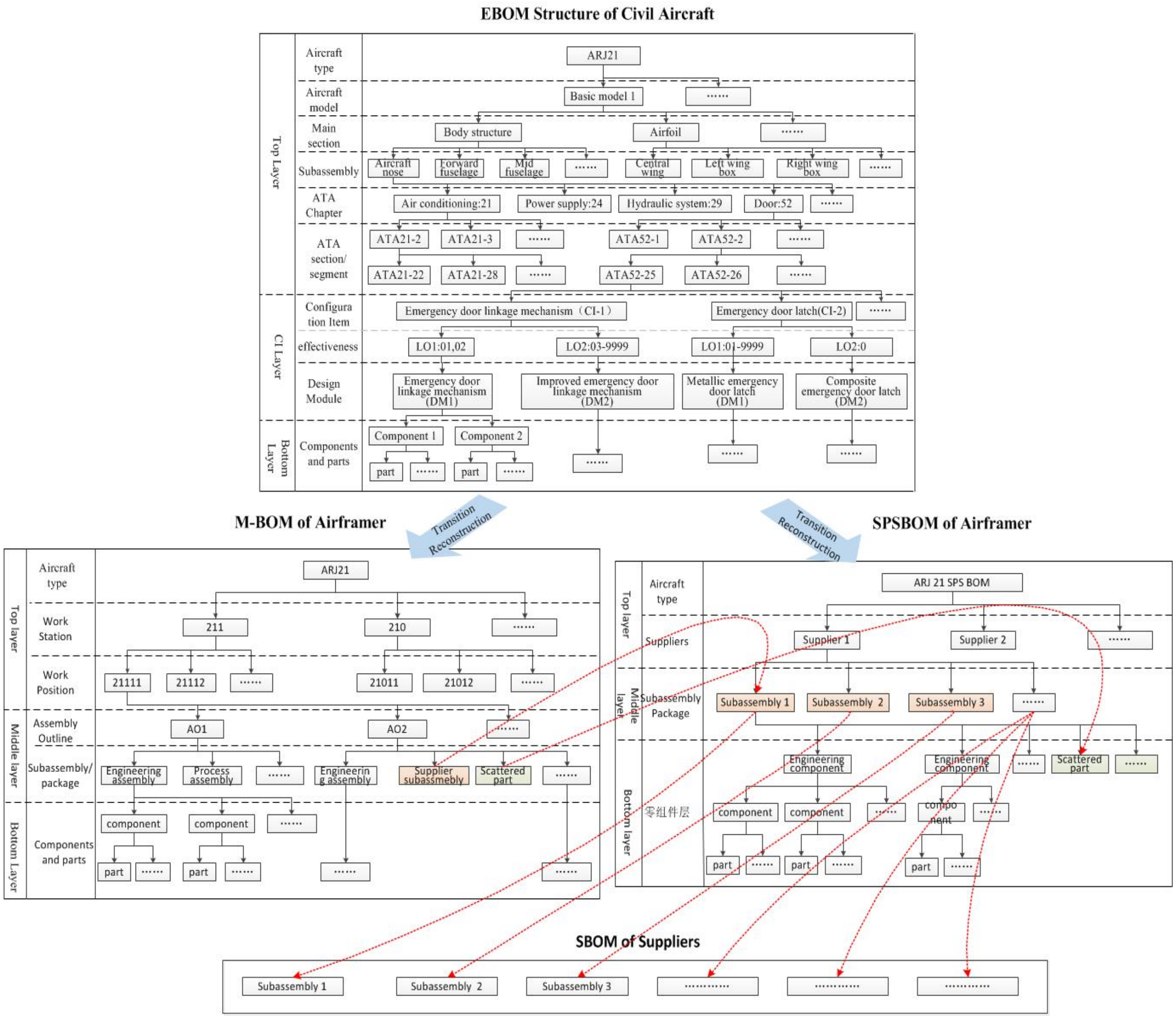

Figure.1 EBOM, M-BOM, SPSBOM And SBOM Of Aircraft

manufacturing and assembly process. The Convenience of manufacturing and assemble is considered as the paramount factor during the construction of the manufacturing BOM. So the structure of engineering BOM and manufacturing BOM are definitely different. But these differences does not mean the data inconformity errors. In the following, the changes of product structure during the BOM transition and reconstruction are illustrated and divided into several forms.

(1) Eengineering parts transform to the process parts by the positional shift of sub-part

For the convenience of fabrication and assembly, Part G is moved to the Part I and J together to form a new process components during the BOM transition as showed in figure 2 Case 1. Part G in this case is moved from one branch to another branch, and their parent components form new process components.

(2) Engineering component disappear by the positional shift of its sub-parts

In figure 2 case 2, parts in a branch of the engineering BOM are replaced in other branches for the assembly during the transition with the form of a new process components, and the original parent

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engineering components will no longer appear in the manufacturing BOM.

(3) Scattered engineering parts collected together to form new process components

In figure 2 case 3, scattered engineering parts in a branch of the engineering BOM, are collected together to form a new process components in the manufacturing BOM, and the engineering parent node also convert into process components.

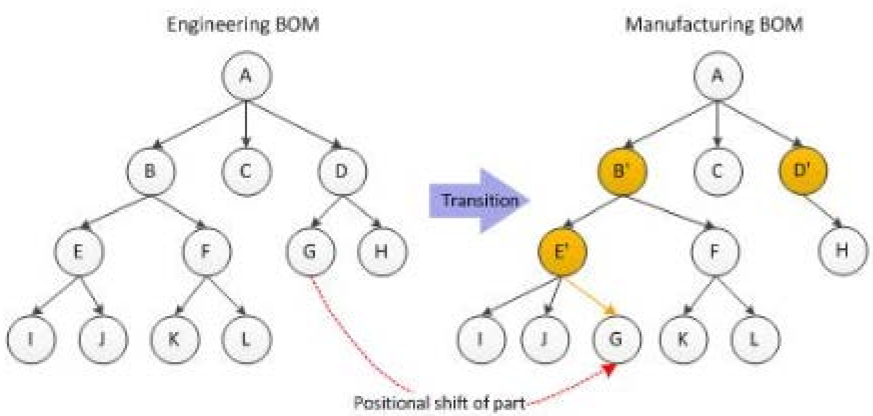

Figure 2. The Deformation Of The BOM Structure In Transition Process (Case 1)

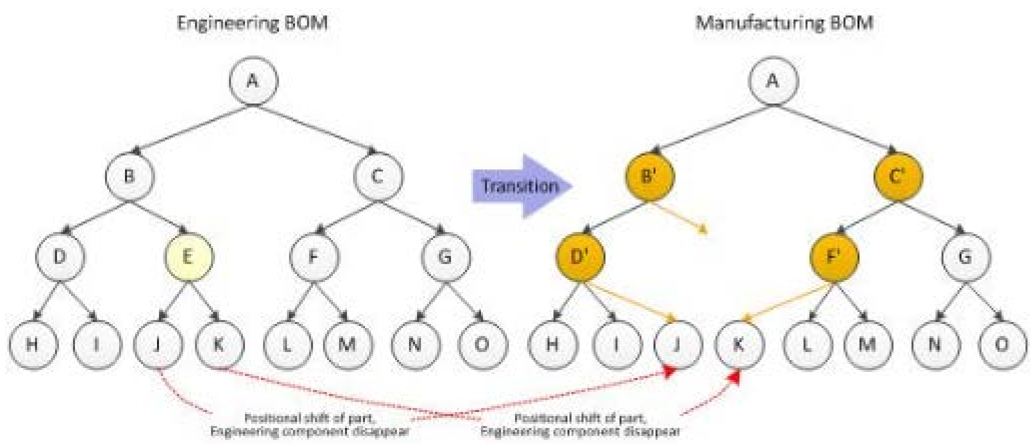

Figure 2. The Deformation Of The BOM Structure In Transition Process (Case 2)

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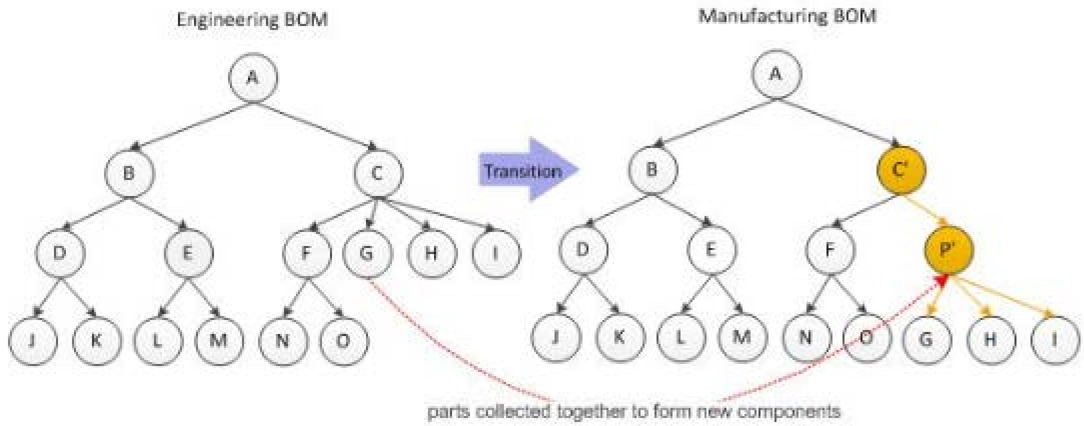

Figure 2. The Deformation Of The BOM Structure In Transition Process (Case 3)

(4) Numerous engineering parts split in the manufacturing BOM

Previously described are all about the result of the structure changes during the movement and the re-combination of the part objects. The following will take into account the splitting of the number of parts. In the figure 2 Case4 of Figure 1, Part H has 10 quantities in the branch D. In the transition for the requirements of assembly, five Part H are kept in the original D branch, the other five Part H are moved into the branch E next to D. The number of H is split in this process, while the formation of the new process components D 'and E '. And the more complex one is showed in the Case5 of Figure 2. In this case, the Part H appears a plurality of positions in the engineering BOM. During the transition and reconstruction process, Part H is assigned to different process component branches. And in such circumstances it is difficult to determine the one-to-one relationship of Part H in manufacturing BOM and engineering BOM.

(5) The merge of the part quantity to form a new process components

In the Figure2's Case 6, Part H which has numerous quantities appear at multiple location, and they are collected together in the manufacturing BOM to form a new parent process component.

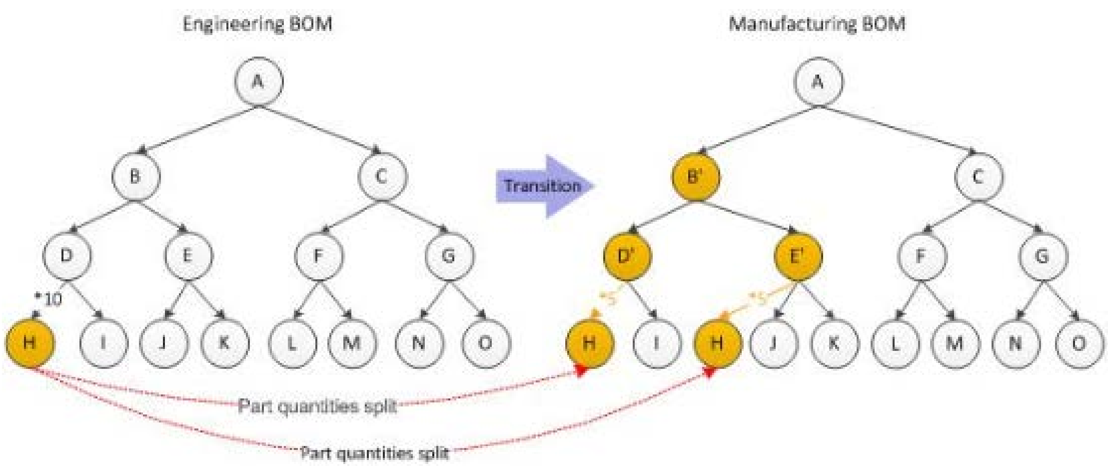

Figure 2. The Deformation Of The BOM Structure In Transition Process (Case 4)

Journal of Theoretical and Applied Information Technology
10th February 2013. Vol. 48 No.1

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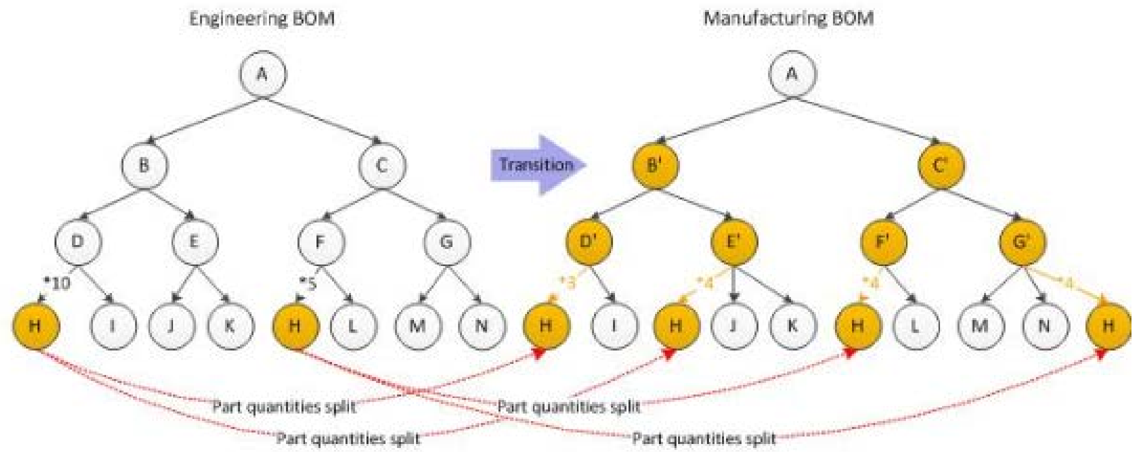

Figure 2. The Deformation Of The BOM Structure In Transition Process (Case 5)

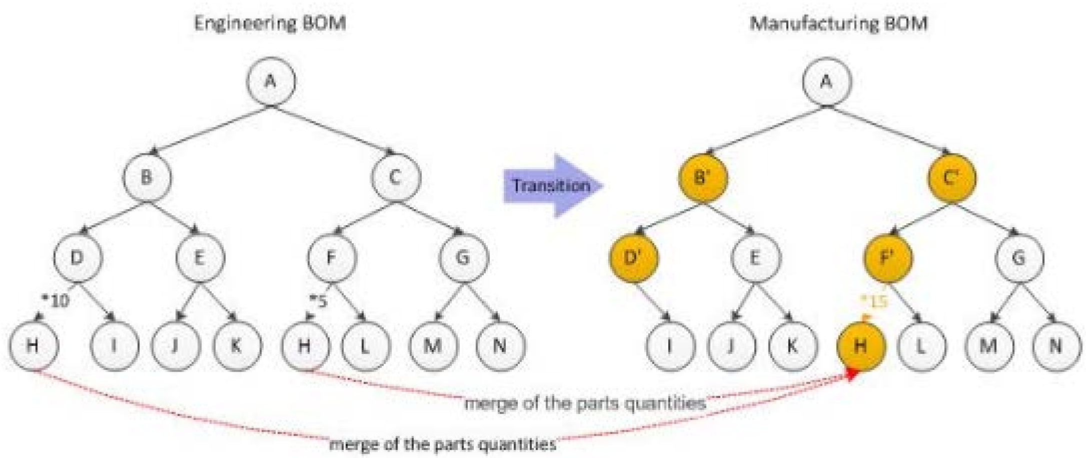

Figure 2. The Deformation Of The BOM Structure In Transition Process (Case 6)

3.3 Inconformity Analysis

The structure of engineering BOM is generally organized according to the product function, however manufacturing BOM is formed considering manufacturing process, manufacturability and assemblability. The changes made during the reconstruction from engineering BOM to manufacturing BOM have been illustrated in above. These differences caused by the parts activities of movement, quantity spilt and merge are normal inconsistency which are mainly due to separation of design and manufacture. And the data inconformity in the product data management, which is erroneous inconsistency such as the structure difference, inconsistent of part quantity and version and should be found by the data inspection in the aircraft configuration management, is caused by the man-made or system-made inconsistency of product information during the BOM transition or engineering change propagation. Therefore, the inconformity inspection method must completely identify the erroneous inconsistency and normal inconsistency, and take the erroneous inconsistency as the final result. On the base of data structure and differences analysis, in the following a relation based conformity inspection method is proposed according to the practical requirements.

4. PRODUCT STRUCTURE RELATION BASED CONFORMITY INSPECTION METHOD

4.1 Algorithm

Product BOM structure is a complex tree. The smallest units which are the tree composed of are branches. Therefore, the tree structure comparison can base on the smallest branch. For EBOM structure, the smallest branch unit includes the

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parent node, child node and the corresponding relation (link relation) of them. The difference between engineering BOM and manufacturing BOM would be found through the comparison of link relation in engineering BOM to the attribute relation in manufacturing BOM, showed in Figure 3.

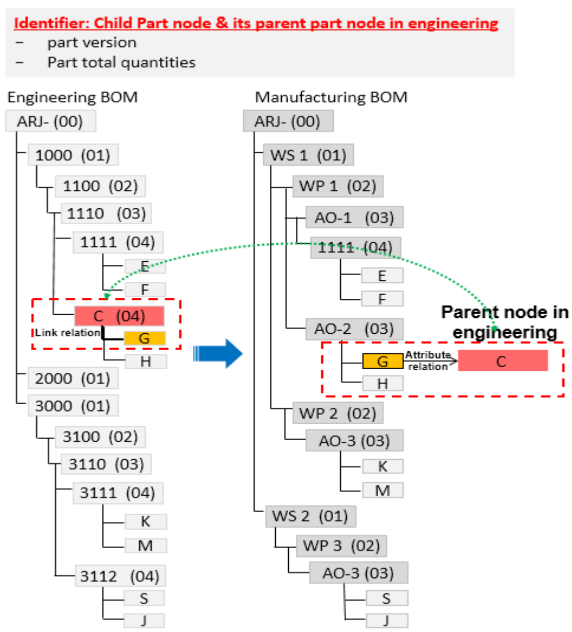

Figure 3. Schematic Of Product Structure Relation Based Method

(1) The scope of conformation inspection

For the civil aircraft which adopts the "airframer-suppliers" business model, its product data conformity inspection has two levels, as showed in Figure 4. The first level is the comparison of the engineering BOM with the whole aircraft manufacturing BOM, which means the consistency inspection of EBOM versus the collection of M-BOM and SPSBOM in this paper, at the same time it should be ensured about the data consistency of scattered parts in M-BOM and SPSBOM. The second level is to ensure the consistency of the SPSBOM and SBOM to keep the conformity of supplier subassembly requirement and final delivered physical product. The conformity on the product configuration management must make sure the BOM data consistency of the two levels mentioned above. Although the scope of comparison and the form of the product data structure different in the two levels are different, but the core data comparison method is the same, and the specific algorithm will be described in detail below.

(2) The mathematical expression of the algorithm

The main idea of the product structure relation based conformity inspection algorithm takes the branch, child part and its parent engineering assembly, as the identifier to search the corresponding attribute relation in the manufacturing BOM and compare the information on the part quantities and version.

Figure 4. Scope Of The Conformity Inspection

The mathematical definition of entire algorithm is in the following.

1) Definition of BOM data

First the BOM data should be defined. The manufacturing BOM are similar to the engineering BOM in the data structure, so are the definition.

e_i: A node of the engineering BOM, in practice it is a part or a component with the part number $e_i.name$, version number $e_i.version$, quantities with hierarchy $e_i.quantity$, and its' engineering parent node $e_i.efather$.

m_i: A node of the engineering BOM, in practice it is a part or a component with the part number $m_i.name$, version number $m_i.version$, quantities with hierarchy $m_i.quantity$, and its' engineering parent node $m_i.efather$.

E: the data set of engineering BOM can be defined as

$$E = \{e_1, e_2, e_3 \dots e_i\} \quad (1)$$

M: the data set of manufacturing BOM can be defined as

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10th February 2013. Vol. 48 No.1

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$$M = \{m_1, m_2, m_3 \ldots m_i\} \quad (2)$$

2) Merge records by identifier and draw the compare result

Before the conformity inspection, the data of engineering and manufacturing BOM should be merged according to the identifier "child node and parent node" separately. Take engineering BOM data for example:

$$eId_i.identifier = \{e_i.name, e_i.efather\} \quad (3)$$

$$eId_i.quantity = \sum_{i=1}^{n} e_i.quantity \quad (4)$$

$$eId_i.version = \bigcup_{i=1}^{n} e_i.version \quad (5)$$

where $eId.quantity$ is the total quantities of parts in engineering BOM which have the same identifier, $eId.version$ is the collection of the parts version which have the same identifier, n is appearing times of $e_i.name$ in the engineering BOM, and after it draw the new record set E' and the respectively record eId_i. The same merge operation according to $mId_i.identifier$ is done to the data set of manufacturing BOM, draw the corresponding record set M', and the respectively record mId_i. The product data difference set D is the symmetric difference between E' and M'.

$$D = E' \oplus M' \quad (6)$$

4.2 Workflow of Inspection Method

The inspection algorithm includes forward and reverse comparison between product engineering data and manufacturing data. The workflow of the inspection method is described in the following, and it can be divided into three stages (as shown in Figure 5):

Stage 1: data import and pre-processing. Import the engineering BOM and manufacturing BOM data, pre-process these data including calculating the part quantities according to the hierarchy, merging the data records with identifier, unifying the part version, judging the part type and filtering process parts by the rule. Then store all the processed data into the database.

Stage2: differences computation. Draw the differences result set D' according to the comparison respectively between $eId_i.identifier$, $eId.version$, $eId.quantity$ and $mId_i.identifier$, $mId.version$, $mId.quantity$ with operation of symmetric difference

Stage3: difference type judgment and the workflow ends.

5. APPLICATION SYSTEM AND ITS VERIFICATION

Based on the above analysis and algorithm, we have developed an application software for the civil aircraft conformity inspection on product configuration management. The system and the algorithm is developed by the Java language and database Oracle. The following diagrams of figure 6, 7, 8 are the demonstration about the database table structure and software page.

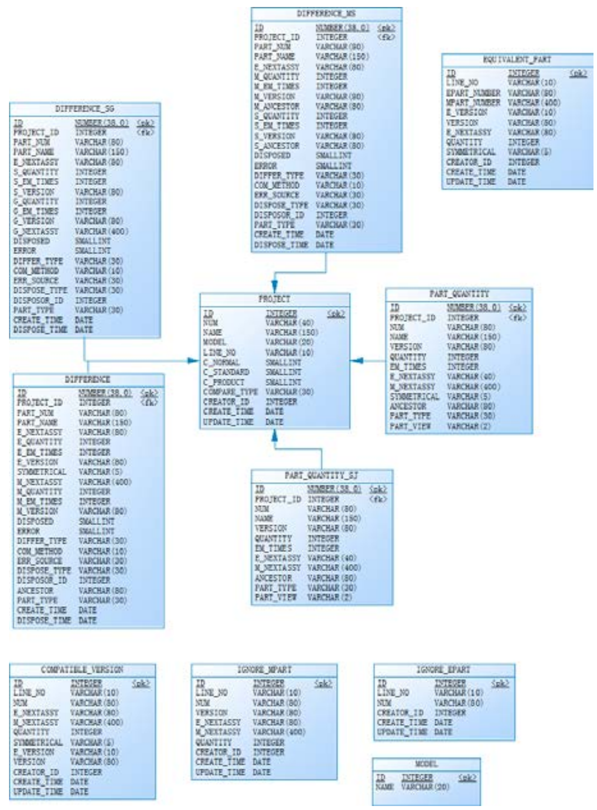

Figure 6. Database Table Structure Of Civil Aircraft Conformity Inspection System

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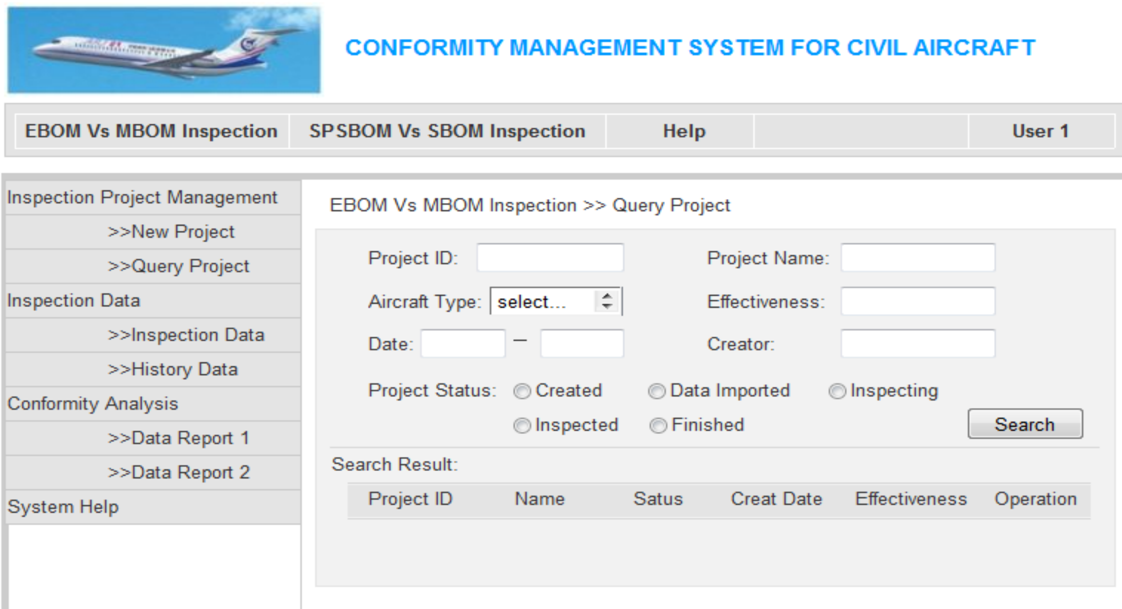
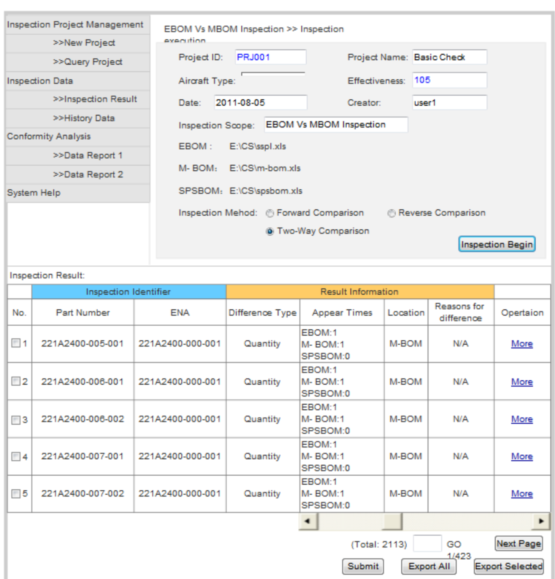


Figure 7. Homepage Of Civil Aircraft Conformity Inspection System

The research method of this paper was applied by the Shanghai Aircraft Manufacturing Co.Ltd. in its' product configuration management for aircraft ARJ21-700. The following in figure 8 demonstrates the developed conformity inspection system and application results.



	Inspection Identifier		Result Information				
No.	Part Number	ENA	Difference Type	Appear Times	Location	Reasons for difference	Opertaion
1	221A2400-005-001	221A2400-000-001	Quantity	EBOM:1 M- BOM:1 SPSBOM:0	M-BOM	N/A	More
2	221A2400-006-001	221A2400-000-001	Quantity	EBOM:1 M- BOM:1 SPSBOM:0	M-BOM	N/A	More
3	221A2400-006-002	221A2400-000-001	Quantity	EBOM:1 M- BOM:1 SPSBOM:0	M-BOM	N/A	More
4	221A2400-007-001	221A2400-000-001	Quantity	EBOM:1 M- BOM:1 SPSBOM:0	M-BOM	N/A	More
5	221A2400-007-002	221A2400-000-001	Quantity	EBOM:1 M- BOM:1 SPSBOM:0	M-BOM	N/A	More

Figure 8. Application Of The Conformity Inspection System

6. CONCLUSION

Civil aircraft as a special product, has tremendous amount of data and complex product data evolution process, and it also has high product security requirements. During the development of the aircraft, the manufacturer has to make the conformity inspection between design and manufacturing for the product data management requirements to obtain the airworthiness certification. On the background of ARJ21-700's development, this paper analysis the product data structure differences in multi-BOM and its causes. Then the data structure relation based inspection method is proposed, and the algorithm of the method is defined with set theory. The workflow of the method is described in detail. Finally the system tool is developed and applied in the ARJ21-700's product management. The application result shows that the method and its tool can effectively help the enterprise to find the inconsistency of the product data, and provides the support to the civil aircraft conformity inspection. In this paper the algorithm is not very perfect for recognizing the normal inconsistency, the intelligent algorithm based on the rules and knowledge will be in important aspect of study.

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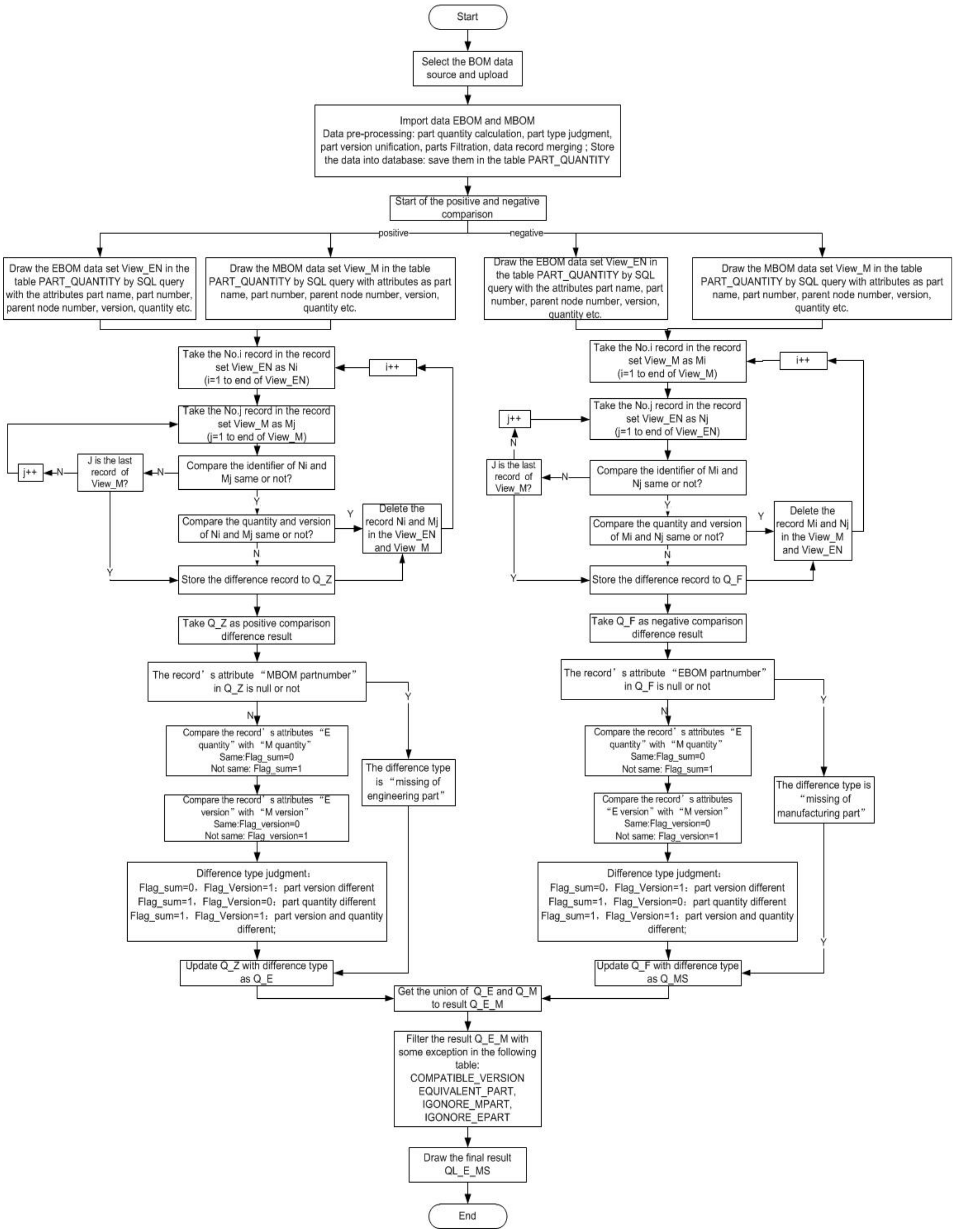

Figure 5. The Workflow Of The Product Structure Relation Based Inspection Method

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