Research on the Matrix-based Version Validity of BOM in Aviation Industry

Sheng Leng , Weifang Chen, Wantai Ma

***Abstract*— Based on the requirements of high-variety and small-batch production in Aircraft manufacturing enterprises, BOM (bill of material) is of great importance during the lifecycle of the products. With the introduction of the relationship between the matrix and the version validity, the validity management of BOM version was provided by the method of the operations of matrix. The reverse consult and the alternating algorithms are proposed embed in the validity matrix structure of BOM. To illustrate the effectiveness, a case study is conducted and shown that it is reasonable and feasible to settle the version management of the BOM in its lifecycle and satisfy the flight management in aircraft manufacturing.**

***Index Terms*— BOM, Version Validity Matrix, Aircraft Manufacturing**

I. Introduction

Aircraft manufacture technologies are undergoing significant changes driven by the need to achieve performance and economic targets. The emergence and growth of rapid prototyping/fabrication technology could revolutionize the manufacturing management. To capture the benefits of the high-variety and small-batch manufacturing model, the products are often arranged in lots and line-units in aviation industry. The manufacturing management system such as ERP/PDM/MES (enterprise resource plan/product data management/manufacturing execution system) applied in those companies should provide the BOM for every lot so much as every line-unit of the airplane. Obviously this will rapidly increase the storage of the BOM in database especially in the design and reengineering stages[1-4].

There are many limitations of the traditional BOM structures which are not convenient in such new environment. During the product lifecycle of the aviation parts, the problems are as follows[3-5]:

1) In the design or the trial production period of the new flight type, the alternating of the BOM is frequently occurred because of the improvable of the design.

2) Because of the unstable manufacturing process which is caused by the small or single batch production, it is necessary to modify the BOM, especially the MBOM.

3) There are mass of items and components in an aircraft. But some of them are in batch production while some of them are in single production. It is very difficult to trace and reverse consult the items which are adopted finally in the aircraft if the BOM is not support such function.

It is the challenge for the version management of the BOM. The data structure and the algorithm of the operations of the BOM will directly affect the application of the BOM in manufacturing management systems[7]. The research on the BOM mapping from its different views in different phases has received a lot of attention recently[6,8–11]. However, the version management has been overlooked.

A Matrix-based version validity structure of BOM is proposed in this paper based on the lots and line-units management in the lifecycle. The application in the MES in a certain aircraft company can improve efficiency.

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II. The Definition of the Validity Matrix of the BOM

During the manufacturing of the aircraft especially the new developed flight, the aircrafts in different lot or different line-unit may have the different configurations although they are the same flight type. These products have the property of the high similarity in their BOMs. So the different line-unit should be distinguished easily in its BOM. Obviously the BOM data of different version which belong the same products in same flight type may greatly extend the database if the structure of the BOM is not well designed. It is a big redundancy referring to the property of the high similarity. Aiming at reducing the redundancy, simultaneity, providing the version management, the validity matrix can be adopted.

The following notations are used in the development of the mathematical model:

B_{all} : The matrix of the items list of every line-units of the product P, $B_{all} = \begin{bmatrix} b_1 & 0 & \cdots & 0 \\ 0 & b_2 & & \\ \vdots & & \ddots & \\ 0 & & & b_n \end{bmatrix}$;

B_i : The set of the items list in certain line-unit i of the product P. $B_i = (b_1, b_2, \cdots b_k), k \le n$;c

Define:

V: The n×m-order matrix of validity, n is the item's amount, m is the line-unit sequence number.

As soon as the validity matrix V is set, the BOM of the line-unit i of product P should be:

$$P_{BOM} = B_{all} V \tag{1}$$

where P_{BOM} is the n×m-ordecr BOM matrix of the whole line-units of product A. Refer to (1), the items list in line-unit i should be :

$$B_i = P_{BOM} e_i = B_{all} V e_i \tag{2}$$

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In Equation (2), the e_i is the m-dimension fundamental vector which element i is 1,and the other elements are 0. $e_i = \{0,0,\cdots 1,\cdots 0,0\}$.

There are different BOM at different stages of the product lifecycle. For instance, the production stages involve the Engineering BOM (EBOM), the process BOM (PBOM), the Manufacturing BOM (MBOM) and the Quality BOM (QBOM). All of them may have variable versions to be stored or to be consulted. But the way of version management according to the lot and the line-unit may be the same.

If there are some quality problems after product is delivered to customers or the product is reordered, it will be convenient to check out the BOM refer to (1) and (2). By setting up the BOM tree, the more detail information can be get from the database.

III. The Data Structure of the BOM

Analyzing the equations shown above, the data structure of the BOM can be set up easily. All the items shown in every version of the product may be just stored once so long as the row vector in the validity matrix *V* is used as the issue number of the version. With the operation of the matrix shown in the equation (2), the BOM list of a certain line-unit can be checked out.

Based on the definitions described above, the entities in the conception model of the database are required to store the BOM with its version information which are shown in Figue1.Table ITEM records the basic information of each item. Table BOM records the item's Father-Son relationship which indicates the assemble information of the product. Table MATER_BOM records the raw material of the item. Table HMATER_BOM records the accessories. Table TOOL_BOM records the cutting tools and the jigs. Table ISSUE_DEPLOY is the version configuration entity which records the e_i , line-unit information and the version names easy for communication.

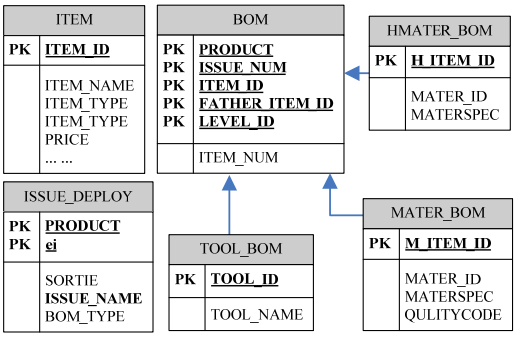

Fig. 1. The conception data modal of the entities of BOM

This conception data model fulfills the requirements of the version and the line-unit management in those aircraft manufacturing company. The complex tree structure of BOM is well described for the optimized data model.

IV. The Algorithm of Reverse Consult and Alternating the BOM

There are all kinds of BOMs with multi-views in every department of companies. All of the departments need the operation of BOM. In order to improve the efficiency of consult, to reduce the dependence of different software architecture, to simplify and modularize the programming, a series of internal standard BOM operations algorithms are set up as stored procedures or packaged as component models for calling in different view of BOM.

A. *Reverse Consult the BOM*

Reverse consult the BOM is in order to find an item's adscription of which version and which product. For example, a certain part may be assembled in many products; also it may be adopted in different versions while in one product.

The algorithm is proposed as follows and the programming flow diagram is shown in Fig. 2, assuming that the item is used in s locations of m versions of product A.

Step 1. Check out the items from table BOM where the "ITEM_ID" is given. Insert the results to a table TEMP1.

Step 2. Count the amount of the item in its certain location and certain version of BOM in table TEMP1 refer to (3). Insert the information into table TEMP2.

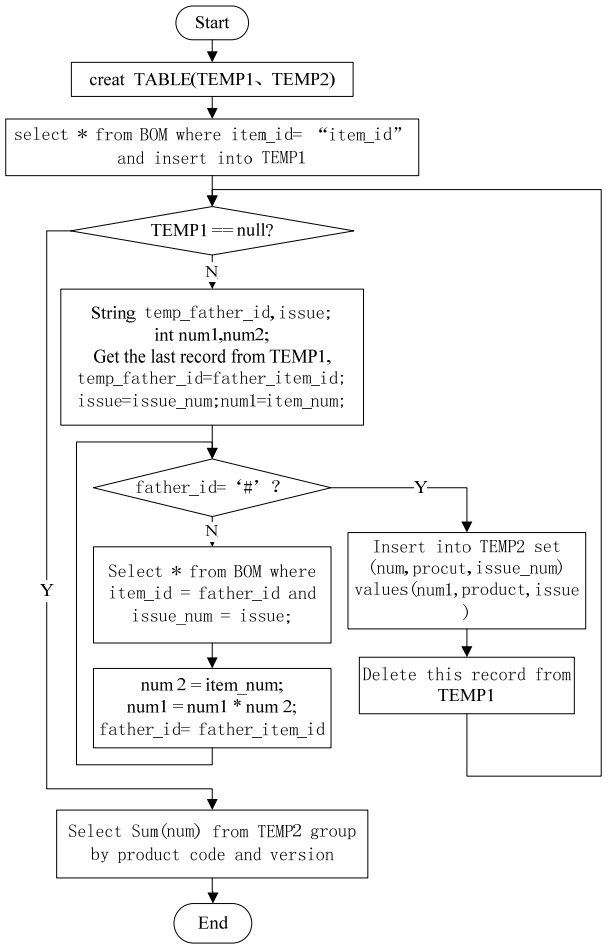

Fig. 2. Flow diagram for the reverse consult of BOM

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$$n_{location} = \prod_{i=1} n\_ITEM\_NUM_i$$
$$if \quad ITEM\_ID_{i+1} = FATHER\_ITEM\_ID$$
$$then \quad n\_ITEM\_NUM_{i+1} = n\_FATHER\_ITEM\_NUM_i$$
(3)

$n_{location}$: The amount of the item in a certain location in BOM structure.

$n\_ITEM\_NUM_i$: The ITEM_NUM of the item in table BOM.

$n\_FATHER\_ITEM\_NUM_1$: The ITEM_NUM of the item's father node.

Step 3. Check out the PRODUCT_ID, ITEM_ID, ISSUE_NUM from table TEMP2, and sum the amount of the item in product A with in different version refer to (4).

$$N = \varphi V \tag{4}$$

where:

N: $N = (u_1, u_2, \cdots, u_m)$ the $1 \times m$ -order matrix. The m denotes the version number. The u_i denotes the amount of the item in version i in product A.

$\varphi : \varphi = (q_1, q_2, \cdots, q_s)$, the s-dimension vector q_i denotes the amount of the item in different location i.

V: $V = (v_1 \quad v_2 \quad \cdots \quad v_s)^T$ the validity matrix of the product A. v_i is m-dimension vector which denotes the version number of the item.

B. BOM Alternating

Under the requirement of alternating the existed BOM during its product lifecycle, it is necessary to transform the existed BOM to a new version, while the previous version is still need to be preserved as an old one.

Step1: Modifying the BOM list in version B_{m+1} refer to (5). The validity vector is set as: $v_{m+1} = [v_i]_{1\times n}, (v_i \in (0,1))$.

$$B_{m+1} = B_{all} v_{m+1}{}^T \tag{5}$$

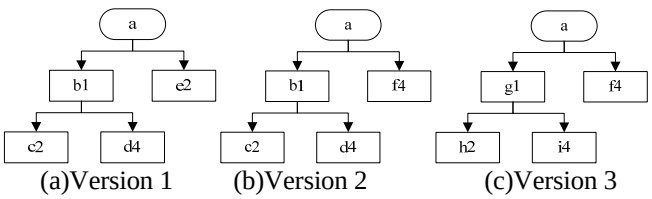
Step2: The new version's validity matrix can be got by modifying V based on the equation (6). Where V' is the validity matrix for the new version m+1. $V_{n\times m}$ is the validity matrix before modified.

$$V' = \begin{bmatrix} V & v_{m+1}{}^T \end{bmatrix}_{n\times(m+1)} \tag{6}$$

With the previous version completely preserved, there is small increase of data storage.

V. Case Study

There is a product A with three versions shown in Fig.3. The number following the letter in the figure represents the numerical relationships between the item and the father item. Obviously there are 9 items in the total items list of all versions of the product A.



(a)Version 1 (b)Version 2 (c)Version 3

Fig. 3. Three versions of the BOM of product A

Refer to (1) and (2), the total items list is 9-dimension vector B_{all} is that: $B_{all} = (a \quad b \quad c \quad d \quad e \quad f \quad g \quad h \quad i)$.

The validity matrix $V_{9\times3}$ is:

$$V_{9\times3} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix}^T .$$

The BOM structure of the three versions is:

$$P_{BOM} = B_{all} V$$
$$= \begin{bmatrix} a & & & & & & & & 0 \\ & b & & & & & & & \\ & & \ddots & & & & & & \\ & & & & & & & & \\ 0 & & & & & & & & i \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix}^T$$
$$= \begin{bmatrix} a & b & c & d & e & 0 & 0 & 0 & 0 \\ a & b & c & d & 0 & f & 0 & 0 & 0 \\ a & 0 & 0 & 0 & 0 & f & g & h & i \end{bmatrix}^T$$

A. BOM Check Out

The BOM of certain line-unit in version 2 can be checked out through the operation as follows:

$$B_i = P_{BOM} e_i$$
$$= \begin{bmatrix} a & b & c & d & e & 0 & 0 & 0 & 0 \\ a & b & c & d & 0 & f & 0 & 0 & 0 \\ a & 0 & 0 & 0 & 0 & f & g & h & i \end{bmatrix}^T \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$
$$= (a \quad b \quad c \quad d \quad 0 \quad f \quad 0 \quad 0 \quad 0)^T$$

B. BOM Alternating

If there is a new version named version 4 of the product A, it can be got refer to (5). The validity matrix of the new one can be got by the equation (6).

$$B_{m+1} = B_{all} v_{m+1}{}^T$$
$$= \begin{bmatrix} a & & & & & & & & 0 \\ & b & & & & & & & \\ & & \ddots & & & & & & \\ & & & & & & & & \\ 0 & & & & & & & & i \end{bmatrix}_{9\times9} \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix}^T$$
$$= \begin{bmatrix} a & 0 & 0 & d & e & f & 0 & 0 & i \end{bmatrix}$$

$$V' = \begin{bmatrix} V & v_{m+1}{}^T \end{bmatrix}_{n\times(m+1)}$$
$$= \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix}^T$$

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The new version of the product shown in Figure 4 can be got with the relationship description in BOM table.

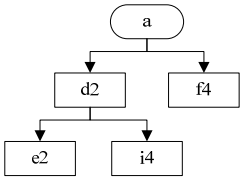

Fig. 4. The new generated version

VI. Application and Conclusions

The validity matrix methods based on BOM version management are adopted in the MES of an aircraft manufacturing company, and the tree structure of BOM is showed in the Figure 5.

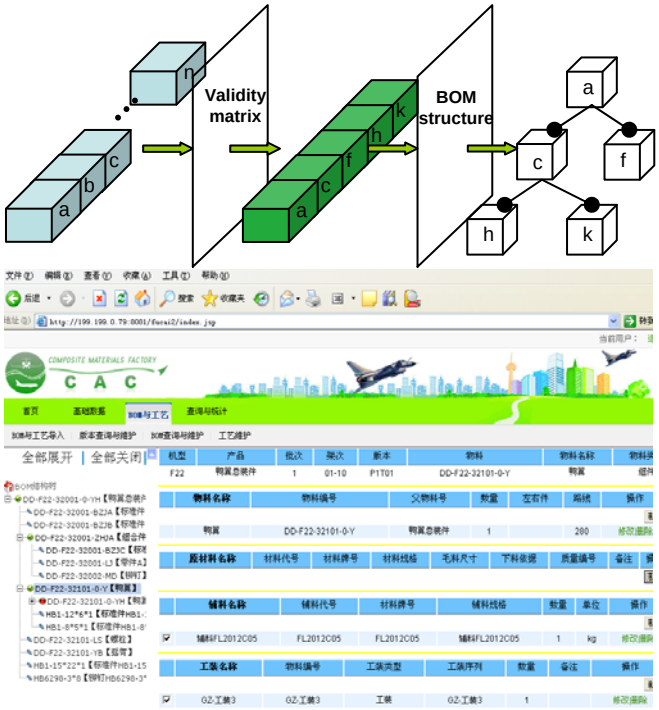

Fig.5. The Application in MES

In recent years, the developing speed of the new products of the aircraft is rapidly increased. Meanwhile the data of the BOM is also increasing remarkably. Adopting the matrix method, the line-unit management of the aircraft is achieved with the unexpanded storage of the BOM of each version for its reduced redundancy of the data. Also it can improve the performance in the application system such as the MES.

For modern manufacturing industries, this method provides a new kind of BOM structure and operation methods which is suitable for the frequent change of the new product.

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