Research on LRU Hierarchy based on Optimal Granularity Level

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Abstract. In order to improve the convenience of replacing faulty equipment on the route and realize LRU(Line Replaceable Unit) level planning reasonably and effectively, a LRU hierarchical division method based on optimal granularity level is proposed. Based on the analysis of the relationship between the components in the product structure, the design structure matrix theory is introduced to construct the comprehensive relationship matrix, which quantifies the relationship between the components from two levels of function and structure. By defining modularization index, combining with the hierarchical traversal of product structure tree, the optimal granularity level is calculated. This method can provide a division scheme based on hierarchical factors for LRU planning and provide support for getting more optimized LRU planning and design.

1. Introduction
The LRU is designed to mainly improve the convenience of replacing the fault equipment on the airline. The maintenance time can be greatly saved and the reliability of aircraft dispatching is improved by the good LRU hierarchical planning. The differences in the granularity of LRU division will directly affect the maintenance support cost and corrective maintenance time size of LRU. Under the normal conditions, the larger the granularity of LRU division is, the simpler it is to locate the fault to the LRU, and the easier it is to isolate the fault, the corrective maintenance time will be reduced, but the corresponding spare part cost of LRU will be increased; the smaller the granularity of LRU division is, the more complex the process of locating the faults to the LRU is, and the more difficult it is to isolate the faults, the corrective maintenance time will be increased, but the cost of LRU spare parts will be decreased. Too high or too low hierarchy of LRU division will all lead to an increase of maintenance costs.

Therefore, it is of great significance for the planning and design of LRU to study the influencing factors of LRU hierarchy division and select the appropriate methods to divide the LRU granularity. The LRU may be a module where several parts are clustered together, it could also be some a fully functional device, or even some a system with a relatively independent structure, there is no direct mapping relationship between the LRU and all layers of aircraft, the granularity of LRU division should give full consideration to the interface relationship between the specific parts, the assembly cost, the time and other factors, and the accuracy and reasonableness are taken as the basic rule. The study of optimal LRU division granularity can provide the division scheme based on the hierarchy factors for the LRU planning, and provide the support for obtaining more optimized LRU planning and design.
2. Association analysis of components based on product structure

In order to realize the quantitative calculation of LRU division, the relationship of different components and parts in the product structure must be described at first. In order to make the description of the relationship between the components more detailed and accurate, the analysis is conducted from the correlation relationship between the two hierarchies of the function and structure.

The functional association between the different components and parts mainly reflects the signal flow, energy flow, material flow, and other transfer of the functional interface, and has embodied the close degree of the function realization of two components and parts, the components and parts that jointly realize some a functional requirement should be aggregated into the modules to improve the independence of functional modules.

The products can usually achieve the multiple main functions, and each function is performed and executed by the multiple parts co-working together. In order to achieve a function, some parts must be together and not detachable, which play a major role in the realization of function, there is a strong functional relationship between them; some parts play a major auxiliary role in the realization of function, then the functional relationship is stronger; some parts play a secondary auxiliary role, then the functional relationship is weak; for the parts that do not play a role in the realization of function, there is no functional relationship. The evaluation criteria of the functional correlation of components and parts are as shown in Table 1.

| Relationship strength | Correlation relationship value | Description |
|-----------------------|-------------------------------|-------------|
| Strong                | 0.8                           | The two components and parts are the first level sub-functions under the same function, of which the function of one part plays an auxiliary role to the function of the other. |
| Medium                | 0.5                           | Both the two components and parts are the first level sub-functions under the same function, and there is an input and output relationship between them, and they are both the necessary functions for the realization of the upper level function. |
| Weak                  | 0.2                           | The two components and parts belong to the sub-functions of different functions, and there is an input and output relationship between them. |
| No                    | 0                             | The functional relationship between the two components and parts does not belong to the above situation. |

The structural correlation of components and parts is mainly reflected in the spatial and geometric structural relations between the components and parts, and the realization of product function is relied on the product structure.

The connection relation, and shape and position relation between the components and parts are mainly considered by the structural correlation. The connection relation includes chemical agent connection, welding, fastener connection, riveting, position-matching, position-limiting and other connection modes. The shape and position relation refers to the perpendicularity, parallelism and other position relation between the parts. The evaluation criteria of the structure correlation of components and parts are as shown in Table 2.

| Relationship strength | Correlation relationship value | Description |
|-----------------------|-------------------------------|-------------|
| Strong                | 0.8                           | The components and parts are closely connected with the strong correlation |
| Stronger              | 0.6                           | There is a certain degree of interaction and correlation |
| General               | 0.4                           | The interaction is weak, and the correlation degree is not strong |
| Weaker                | 0.2                           | There is little interaction between the components and parts |
| No                    | 0                             | No correlation of parts |

3. Establishment of comprehensive relation matrix

The construction of comprehensive relation matrix can quantitatively represent the mutual relation between the components and parts. In order to make the comprehensive relation matrix more detailed and accurate for the description of the relationship between the components, the comprehensive relation matrix is conducted from the correlation relationship between the two hierarchies of the
According to the fuzzy relationship between the components and parts, the weighted average value \( r(i,j) \) of the degree of relation between the components and parts \( i \) and \( j (i,j=1,2,\ldots,n) \) is:

\[
r(i,j) = \left( \sum_{m=1}^{M} r_{fm}(i,j) u_{fm} + \sum_{n=1}^{N} r_{sn}(i,j) u_{sn} \right) / 10
\]

(1)

Where, \( r_{fm}(i,j) \) and \( r_{sn}(i,j) \) are the values of the functional and structural degree of relation between the components and parts \( i \) and \( j \) respectively; \( u_{fm} \) and \( u_{sn} \) are the weights of the functional and structural degree of relation between the components and parts \( i \) and \( j \) respectively, and meet:

\[
u_{fm} + u_{sn} = 1
\]

(2)

Thus, a comprehensive relation matrix \( R \) of the relations between the components and parts can be formed:

\[
R = \begin{bmatrix}
r(1,1) & \cdots & r(1,n) \\
\vdots & \ddots & \vdots \\
r(n,1) & \cdots & r(n,n)
\end{bmatrix}
\]

(3)

Where, \( 0 \leq r(i,j) \leq 1 \), and \( r(i,j) = r(j,i) \) \( (i,j=1,2,\ldots,n) \).

In order to divide the LRU module of product structure tree, the comprehensive relation matrix \( R \) must be converted into the product related design structure matrix \( D \).

The Design Structure Matrix (DSM) was proposed in 1981 by Dr. Steward, an American scholar, which is a specific method to study the analysis and planning of product design process. The DSM matrix is a square matrix made up of a series of row and column elements with the same order, the row and column elements in the matrix represent the design elements in the design process, the non-diagonal cells in the matrix represent the relations between the design elements, the number in the cell represents the relation weight, one domain can only modeled by the DSM method, and the influence relationship between the elements within the domain is analyzed.

To calculate the design structure matrix \( D \), the threshold value \( \lambda \) is suggested to be:

\[
\lambda = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} r(i,j)}{n \times n} (i,j=1,2,\ldots,n)
\]

(4)

Then:

\[
\begin{align*}
D_{ij} &= 0, r(i,j) < \lambda \\
D_{ij} &= 1, r(i,j) \geq \lambda
\end{align*}
\]

(5)

From this, the relevant design structure matrix \( D \) can be constructed.

4. Calculation of optimal granularity level

The correlation matrix \( D \) of matrix \( D \) can be obtained by adjusting the sequence of the parts in the design structure matrix \( D \) according to the sequence of the parts in the product structure tree.

Based on the correlation matrix, the connection condition between the modular components of the product shall be represented by a quantitative Index, the Modularity Index MI. The smaller the MI value is, indicating the stronger the coupling inside the module is, and the weaker the coupling between the modules is, namely, the smaller the MI value is, the closer the connection between the components inside the module is, and the weaker the connection between the components in the different modules is. The MI can be expressed as:

\[
MI = I + Z
\]

(6)

Where: \( I \) represents the number of elements whose modular cluster is "1" in the correlation matrix \( D \); \( Z \) represents the number of elements whose modular cluster is "0" in the correlation matrix \( D \).

The modularization index \( MI \) of each hierarchy is respectively calculated based on the correlation matrix \( D \) according to the divided modularization hierarchy of the product structure tree. According to
the property of modularization index, when the modularization index corresponding to some a degree of modularization is the smallest, then the degree of modularization is optimal, and the corresponding granularity level is the optimal granularity level.

5. Modular index calculation method based on product structure tree

The LRU division needs to calculate each layer l of product structure tree, its modularity index is obtained, and then the optimal granularity level is determined.

5.1. Traversal of product structure tree

The BOM of product structure tree is traversed to determine the number of layers of which each node is located in the product structure tree.

The hierarchical traversal method can be used by the BOM traversal algorithm. The idea of breadth-first traversal is adopted by the hierarchical traversal, namely, the traversal is performed according to the hierarchical order of nodes in the BOM tree, starting from the root node, each layer of nodes in the BOM tree is traversed layer by layer from top to bottom, and each layer of nodes is traversed from left to right one by one, as shown in Fig.1.

![Schematic diagram of product structure tree hierarchical traversal](image)

Fig.1 Schematic diagram of product structure tree hierarchical traversal

The realization of the BOM hierarchy traversal of the product structure tree needs to use a data structure -- a queue.

A queue is a special kind of linear table, its specialness is in that the operation of deletion is only allowed at the front end of the table, while the operation of insert is conducted at the rear end of the table. Like the stack, a queue is a linear table with the limited operations. The end of the insertion operation is called the end of the queue, and the end of the deletion operation is called the head of the queue. When there is no element in the queue, it is called an empty queue.

The data elements of a queue are also called as the queue elements. The inserting of a queue element into the queue is called as the enqueuing, and the deleting of a queue element from the queue is called as the dequeuing. because the queues are only allowed to be inserted at one end and deleted at the other end, only the first elements to enter the queue can be deleted from the queue first, so the queues are also known as the first in first out (FIFO) linear tables.

In order to determine the number of layers in the product structure tree where each node is located, an array is established, and an array unit is allocated for each node, the initial value of the number of layers is 0.

The BOM hierarchy traversal process of product structure tree is as shown in the figure, the specific steps are as follows:

Step 1 Firstly, the root node of product structure tree is placed into the queue.

Step 2 The queue state is judged, when the queue is non-empty, the step 3 to Step 5 is performed in cycle, otherwise, it is finished.
Step 3 The dequeuing operation is performed, one node is obtained, the number of layers corresponding to the node is +1, access to the node.

Step 4 If the left subtree of this node is non-empty, the enqueuing operation of the left subtree of this node is performed, and the the number of layers for the relevant subordinate nodes of the left subtree is the same as the current node.

Step 5 If the right subtree of this node is non-empty, the enqueuing operation of the right subtree of this node is performed, and the number of layers for the relevant sub-nodes of the right subtree is the same as the current node.

The end.

5.2. Modular index calculation method

Some text. The product structure tree BOM hierarchy is traversed to determine the number of layers of which each node is located in the product structure tree. By using the correlation matrix $D$, the modularization index of nodes with the same number of layers is calculated to determine the optimal granularity level.

The specific steps of modularization index calculation are as follows:

Step 1. The initial number of layers is 0.

Step 2 The node with the same number of layer as the current number of layer is selected as the target node according to the array of the number of layers in the node.

Step 3 The determination of the modularized cluster for the current layer. One target node is selected, One modularized cluster consists of the target node and its subordinate nodes, and the several modularized clusters corresponding to the several target nodes are determined.

Step 4 uses the formula (6), for the correlation matrix $D$, the modular index MI of several modularized clusters is calculated as the modular index MI of the current layer.

Step 5 the number of layers +1, repeat step 2 to step 4 until the bottom is reached.

6. Conclusion

In this paper, on basis of the analysis of the correlation relationship of different components and parts in the product structure, the theory of design structure matrix is introduced to build a comprehensive relationship matrix, the interrelation between the different parts is quantified and represented from the two hierarchies of the function and structure. The calculation of the optimal granularity level is realized by defining the modularization index and combining with the hierarchical traversal of the product structure tree, the reasonable and effective realization of LRU hierarchical planning is provided with the support.

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