

Product Structure Analysis Method Based on the Interpretive Structural Modeling

DENG Xiao-lin

Department of Electronic Information Engineering
Wuzhou University
Wuzhou, China,(0)15177689110
dengxiaolin3@163.com

Abstract—The paper analyzes the related research status of the complex network, and studies on construction method of networks of parts relation for products. By applying interpretive structural modeling to the product structure analysis, this article proposes one structure analysis method that based on interpretative structural model. Through utilizing interpretative structural model, network of machinery parts is constructed into a hierarchical structure model that can clearly show what the product structure is and how the product parts are acting on or influencing each other, thus provides the basis for the design.

Keywords—interpretive structural modeling; hierarchical model; product structure

I. INTRODUCTION

The network is a diagram consisting of point set and edge set, and each side in the edge set has a corresponding point in the point set. Complex network theory—a theoretical approach in conjunction with the specific system—mainly researches in the geometric nature of the network, formation mechanism of the network, the structural stability of the network, as well as the statistical regularity of the network evolution.

II. CONSTRUCTION OF NETWORKS OF PARTS RELATION FOR PRODUCT

Machinery products are composed by different types and quantities of components. The development and design process of machinery products involve no longer in the individual parts, but products assembled by a number of parts. Here by complex network theory is introduced to analyze the products. According to the assembly relationship between the various parts in the product structure, a weighted directed acyclic network is built: various parts of the product as the network node, assembly and constraint relations between the parts as the network's edge which is directed. The direction of the edge starts from a node of a certain part to the node constraints in the part, therefore a weighted directed acyclic network is constituted.

III. PRODUCT ANALYSIS THEORY BASED ON THE INTERPRETIVE STRUCTURAL MODELING

This article applies the interpretative structural model to the product structure analysis. Firstly, products are broken down to

the grounds of the complex network of various parts and components and assembly relationships among them. Secondly, based on methods for constructing networks of parts relation for product, networks of parts relation for product are built, thus adjacency matrix of products are established. Reachable matrix can be computed by using adjacency matrix, while the reduced matrix of reachable matrix can be obtained by carrying out strongly connected set of decomposition of the reachable matrix. Finally, by dividing the level, a hierarchical model of the product, which can clearly show the composition and structure of products and interaction between each component and can provide the basis for design, is established.

IV. ANALYTICAL METHODS AND FLOWS OF PRODUCTS

(a)Analyze mechanical products, studying the composition relations between its various parts, and building the relationship network parts and components.

(b)Establish the adjacency matrix of the product according to networks of parts relation for products.

The adjacency matrix is used to represent a direct connection with the matrix between each unit, assuming there are several units (n units)in the system S [5] :

$$S = \{e_1, e_2, \dots, e_n\}$$

Then adjacency matrix is

$$A = \begin{matrix} & \begin{matrix} e_1 & e_2 & \cdots & e_n \end{matrix} \\ \begin{matrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{matrix} & \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \end{matrix}$$

Hereinto,

$$a_{ij} = \begin{cases} 1, & \text{When there is a relationship between } e_i \text{ and } e_j; \\ 0, & \text{When there is not any relationship between } e_i \text{ and } e_j; \end{cases}$$

(c)Compute reachable matrix of products by applying adjacency matrix.

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Reachable matrix is to use a matrix form to describe what extent nodal points in directed graph can reach after a certain length of the channel. Assume that diagram D is a relation graph of system $S = \{e_1, e_2, \dots, e_n\}$ composed of several units (n units). Matrix M, whose elements are

$$m_{ij} = \begin{cases} 1; \\ 0; \end{cases}$$

(In the above formula, $m_{ij}=1$, if it is accessible from e_i to e_j through a number of branches; $m_{ij}=0$, if it is inaccessible from e_i to e_j .) is called the reachable matrix of D. Hereinto, if it is reachable starting from e_i to e_j through k section branches, then k the reachable "length" from e_i to e_j .

The reachable matrix can be computed through the associated matrix. The computing method is as follows:

$$A_1 = (A \cup I)^1, A_2 = (A \cup I)^2, \dots$$

If $A_k = A_{k+1}$, then reachable matrix $R = A_k$.

(d) Carry out strongly connected set of decomposition of the reachable matrix to obtain the reduced matrix of reachable matrix.

Methods[5-6] of decomposing strongly connected set are as follows:

Suppose $R = (R_{ij})_{n \times n}$ is the reachable matrix of system S, while in $R \cap R^T = (R_{ij})_{n \times n} = (r_1, r_2, r_3, \dots, r_n)^T$, r_i is n-dimensional row vector in which the set composed of all the mutually unequal row vector is $\{r_1', r_2', r_3', \dots, r_m' | (1 \leq m \leq n)\}$.

(a) m' is strongly connected subset of System S. In $\{r_1', r_2', r_3', \dots, r_m'\}$, m' is the number of more than one row vector whose component value is one.

(b) If r_i' is more than one row vector whose component value is one, supposing in $ri' (1 \leq i \leq m')$ component whose positive integral solution is one is $r_{ik_1}, r_{ik_2}, r_{ik_3}, \dots, r_{ik_t}, 2 \leq t \leq n$, then set all the weight value of 1, then the subsystem $S' = \{x_{k_1}, x_{k_2}, x_{k_3}, \dots, x_{k_t}\}$ is a strong connected subset.

(e) Divide level to attain hierarchy model of the product.

Level is divided as follows.

If $R_e = (r_{ij})_{n \times n}$ is the reduced matrix of the system S, then $R_e E_{m-1} = [r_1, r_2, \dots, r_n]^T, m \geq 1, n$ dimension vector $E_0 = [1, 1, \dots, 1]^T, E_m = [e_1, e_2, \dots, e_n]^T$ hereinto,

$$e_i = \begin{cases} 0 & r_i \in \{0, 1\} \\ 1 & r_i \notin \{0, 1\} \end{cases}.$$

As to $x_i \in S, x_i$ are level m elements of S when the necessary and sufficient condition is $r_i = 1$.

V. APPLICATION CASES

Below the clamping jaw shown in Figure 1 is taken as an example, describing the methods above-mentioned.

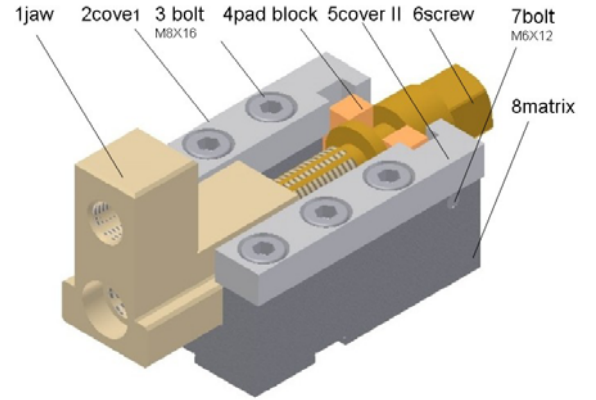


Figure 1. clamping jaw chart

(a) By analyzing the structure diagram of the clamping jaw, we can know that the clamping jaw is made up of see eight different parts. According to the product adjacency matrix construction method, the adjacency matrix of the product can be built.

The matrix A is the adjacency matrix of the product. 1 is for the jaw, 2 the cover I, 3 the screw (Max16), 4 the pad block, 5 the cover II, 6 the screw, 7 the screw (Max12), 8 the matrix.

$$A = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 2 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 5 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 6 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

(b) Using the adjacency matrix computed above calculates the product of the reachable matrix R.

$$R = \begin{pmatrix} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 2 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 3 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 \\ 5 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 6 & 1 & 0 & 0 & 1 & 0 & 1 & 1 & 1 \\ 7 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

(c) By decomposing reachable matrix, the reduced matrix of the reachable matrix is obtained.

Considering the above reachable matrix, we can see that the reduced matrix is the reachable matrix because the matrix has no strongly connected components.

(d) By dividing the level, a hierarchical model of the product is established.

Compute $E_0 = (1, 1, 1, 1, 1, 1, 1, 1)^T$,

then $R_e E_0 = (2, 2, 1, 3, 2, 5, 1, 1)$. The third, seventh and eighth vectors are all valued as one, the corresponding screw Max16 screw Max12 and the matrix are the lowest-rise ($L_1 = \{3, 7, 8\}$).

Value the divided level location as zero, while other bits are reserved for one, then $E_1 = (1, 1, 0, 1, 1, 1, 0, 0)^T$ $R_e E_1 = (1, 1, 0, 1, 1, 3, 0, 0)$. The first, second, fourth and fifth vectors are all valued as one, the corresponding jaw, cover I, pad block, and cover II are the second-rise ($L_2 = \{1, 2, 4, 5\}$), the screw is the third-rise. Figure 2 shows the hierarchical model of the clamping jaws.

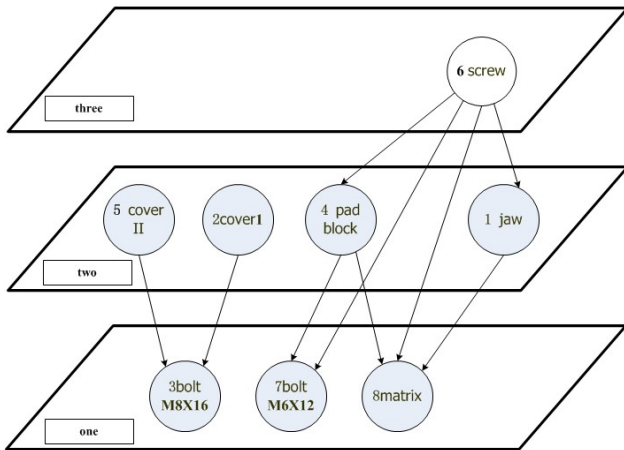


Figure 2. hierarchical model of clamping jaws diagram

The hierarchical model can clearly reflect the relationship of the connection and influence between the various components of the product. The level model diagram analysis shows that the higher the level, the greater influence the parts in the level on the entire product structure. Therefore, modifying the structure and size of such parts should be avoided during improving product design and redesign. For example, the screw in the figure, we should try to avoid changing it. Pad block, it is not the highest level, but because it affects two parts and is impacted by one part, we should also do our best avoid changes in this part. For the cover I and cover II, as they have no in-degrees and it affects the standard bolts, changing the structure and size of the cover to the diversification of products can be considered.

VI. CONCLUSION

By applying interpretive structural modeling to the product structure analysis, this article proposes one structure analysis method that based on interpretative structural model. Product structure hierarchical model constructed using this method can clearly reflect the composition and the relationship among the various parts, and the hierarchical model can distinctly mirror the structure composition of the product, influence and relation among each components, providing the basis for the design. Finally, taking the clamping jaws as an example, the methods described above are verified.

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