Chapter 2
Framework of Rapid Product Cost Estimation Based on the Modular Product Family

Guangxing Wei and Yanhong Qin

Abstract By decomposing the product family into generic modules, the model of a modular product family is established, and the candidate modules which are nearest to the customer requirement can be retrieved by computing the similar degree of module case and the target module on the same module model quantitatively. For the search space is restricted within the generic modules, so it is helpful to reduce the search time and promote efficiency. And then, the cost structure of the different types of modules is analyzed, i.e., the basic module and customized module, and the different cost estimation approaches are applied to different types of modules. Finally, the cost of the customized product can be calculated quickly and accurately by accumulating the cost of modules in each level of the modular product family progressively.

Keywords Mass customization · Modular product family · Cost estimation

Introduction

Mass Customization (MC) is an effective competition strategy to adapt to the fierce change of market. It is committed to achieve a rapid response to a customer and provide the customized product and service at the cost and efficiency close to mass production, which makes most of the manufacturers enter a stage of mass customization [1, 2]. Here, how to estimate the cost of the customized product and quickly quote a price to the customer is the key link to achieve a rapid response to customization. Wang and Tan [3] proposed a cost analysis method based on the demand characteristics to achieve the product cost estimation in the stage of product design, and the method considered all the costs during the lifetime of the product. Liang et al. [4] summed up the models of product cost estimation such as the cost parameter model, the analogy model, and the detailed parameter model, and she pointed

G. Wei (✉)
School of Management, Chongqing Jiaotong University, Chongqing 400074, China
e-mail: wgx777@126.com

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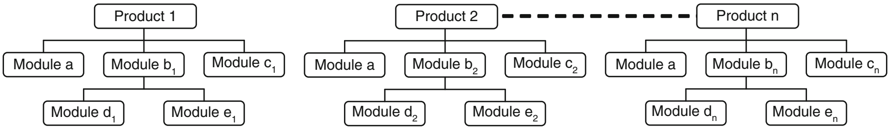
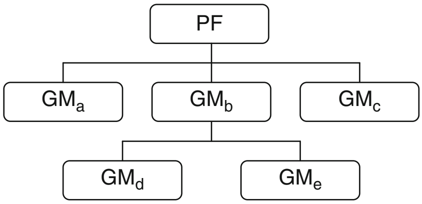


Fig. 2.1 Modular structure of each product in the same product family

Fig. 2.2 Generic module of product family



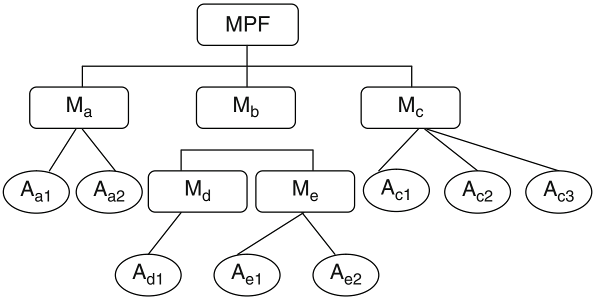
out the merits and shortness of each model. As well known to us, the design for a product family based on modularization is an effective method to achieve MC at a high efficiency and at a low cost, and all the products in the same product family have the same product structure, therefore, the cost parameters of them are the same, but the detailed information of each parameter is different. Therefore this chapter will propose a cost estimation framework for the customized products based on the modular product family model, which can integrate the merits of the cost estimation methods discussed above.

This chapter will be organized as follows. Section 2 will decompose the product family into various generic modules from top to down, and then the module model for each generic module will be established and denoted by attribute variables. The value of the attribute variables can be obtained by transferring the customer requirement by a product planning matrix and by the module deployment matrix, as we have researched [1], and the modules retrieved from the generic modules can be revised to meet the customer requirement. In Section 3, the cost structure of the modular products in a product family will be analyzed, and we will adopt different cost estimation methods for the basic module and the customized module. Finally, we can get the satisfactory product by combining the modules from bottom to top along the modular product family model, and at the same time the cost of the final product can be calculated quickly and accurately by accumulating the cost of the module at each level in a certain sequence.

Model of Modular Product Family

According to our relevant research work [1] and [6], Fig. 2.1 illustrates the modular structure of a single product in a product family, while Figs. 2.2 and 2.3 illustrate the product family which is represented as the root node of the tree, decomposing the product family into various GMs (Generic Modules) and module model respectively.

Fig. 2.3 Module model of modular product family



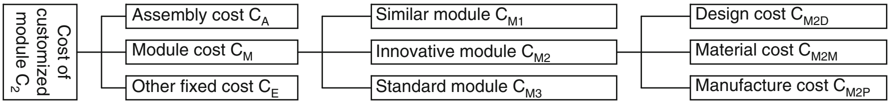


Fig. 2.4 Cost structure of **customized module**

In general, on the assumption that M denotes the module model, $\{M_1, M_2, \ldots, M_m\}$ can denote the product family. $M_i\,(i = 1,2,\ldots m)$ is a random module model in $\{M_1, M_2, \ldots M_m\}$, and the set of attribute variables $A(M_i) = \{A_j(M_i)\,|\,j = 1,2,\ldots,n_i\}$ expresses M_i. The number of attribute variables in each module model may not be equal, therefore n_i denotes the number of attribute variables in the ith module model. Analogously, the set of attribute variables $\mathrm{A}(MPF) = \{A_j(M_i)\,|i = 1,2,\ldots m; j = 1,2,\ldots,n_i\}$ can express the product family. If $a_j(M_i)$ implies the value of the jth variable $A_j(M_i)$ of M_i, then $D_j(M_i)$ denotes the domain of $A_j(M_i)$.

Cost Analysis for Different Types of Module

In general, the cost parameters are different for different products, but the cost parameters are the same for the products in the same product family. For the same reason, the modules derived from the same module model are similar in material, geometry, process method, and manufacture mode, so that the cost of module in need can be calculated by revising the cost of a similar module. In the modular product family, there are basic modules and customized modules, and the customized modules can be classified into three types further: standard module, similar module, and innovative module, as illustrated in Fig. 2.4.

In C_M, the cost of the similar module C_{M1} can be estimated from the cost of the similar module in case base, but the cost of the innovative module C_{M2} can be calculated by add together the design cost C_{M2D}, the material cost C_{M2M}, and the manufacturing cost C_{M2P}. So the cost of the customized module can be denoted as following:

$$C_2 = C_A + C_M + C_E = C_A + [C_{M1} + (C_{M2D} + C_{M2M} + C_{M2P}) + C_{M3}] + C_E. \tag{2.1}$$

In the formula:

(1) Assembly cost C_A: C_A is mainly relative to difficulty of module assembly, assembly precision, and assembly sequence, and it can be denoted as:

$$C_A = K_1 \sum_{t=1}^{T} F_t + K_2 S \qquad t = 1,2,\ldots T, \tag{2.2}$$

where F_t denotes the difficulty of module assembly, S denotes the sequence of assembly, K_1, K_2 are the coefficients of adjustment of F_t, Saccordingly, and T denotes the number of modules. The difficulty of the module assembly relies on the character of module assembly, including the degree of a free module, accuracy of the module assembly, and the ratio of module size to the entire assembly volume. The factor infecting the assembly sequence R includes: design level of the module, manufacturing grades of the module, the requirements of module assembly on the assembly fixture, the parallel degree of assembly sequence, and so on. The products in the same product family have the same process of assembly, so MC enterprise can adopt the exible manufacturing technology to manufacture these customized products at the efficiency close to a large-scale assembly, and the assembly cost C_A is constant, which can be regarded as fixed cost with C_E.

(2) The cost of the similar module C_{M1}: It can be calculated based on the similar module case. The similar modules can use similar or same resources and processing methods to manufacture, resulting in similar costs. Some parameters relative to modules can be filtered out to compute the similar degree between modules, and then the cost of modules in need can be obtained by revising the original and similar module case quickly. For example, the main cost parameters of modules include: he material parameters (such as material type, unit price of material, material weight, etc.) and the processing parameters of modules (processing type, processing technology, and precision, etc.). Some relation between these parameters and attributes of modules can be established,; when the value of attribute variable is changed, the cost of a new module can be calculated. Some literatures introduced the algorithm of Wavelet network [5] and [6], which set the relation between the attribute variable and the module cost by emulating the data, and then the data about the cost of similar modules are inputted to compute the cost of new modules in need.

(3) The cost of the innovative module C_{M2}: It is made up of a design cost C_{M2D}, a material cost $C_{M2M,}$ and a manufacturing cost C_{M2P}. The design cost C_{M2D} can be computed by resources spent on the design (the available . . . specific statistics can be investigated from the financial sector). The material cost C_{M2M} equals the module volume V_M multiplied by the unit price of material P_M, i.e., $C_{M2M} = V_M\ P_M$.

(4) Cost of the standard module C_{M3}: The cost of the standard module can be obtained from the historical cost data, or from bargaining with the supplier by outsourcing the manufacture of the standard module. So the cost of the innovative and the similar module is the key to the cost estimation based on a modular product family.

Other cost C_E: Other cost includes the cost spent on adjusting tools, setting the metal cutting speed and feeding rate, programming the same or similar parts of manufacture, fuel and energy cost, and the overhead cost relative to the product and service.

Cost Computation Driven by Requirement

To calculate the cost of customized products, similar products should be retrieved, and then we modify or create a module and finally estimate the cost of the customized products. For example, the search algorithm on the module model M_i is as following:

Step 1. According to the requirements translation above, the customer requirements of the attribute variable of each module model can be obtained. For a random module model M_i, the set of its attribute variable is $A(M_i) = \{A_1(M_i), A_2(M_i), \ldots A_{n_i}(M_i)\}$. In Sect. 2, the customer requirements on the module model M_i can be translated into the value requirement of an attribute variable, i.e., $a^r(M_i) = (a_1^r(M_i), a_2^r(M_i), \ldots a_{n_i}^r(M_i))$ and the weights vector $w^r(M_i) = (w_1^r(M_i), w_2^r(M_i), \ldots, w_{n_i}^r(M_i))$, which denote the target module.

Step 2. If a module case u is a random case of GM_i and the value vector of an attribute variable is $a^u(M_i) = (a_1^u(M_i), a_2^u(M_i), \ldots, a_{n_i}^u(M_i))$, $u = 1, 2, \ldots, v_i$, where v_i denotes the number of module cases in GM_i, searching all the module cases of GM_i, i.e., compares the target module and each module case of GM_i.

Step 3. The similarity of the target module and each module case in GM_i can be computed out, i.e., $s^u(M_i) = 1 \quad \sum_{j=1}^{n_i} w_j^r(M_i) \; {}^u_j(M_i)$ and ${}^u_j(M_i)$ denotes the distance between $a_j^r(M_i)$ and $a_j^u(M_i)$, and it is relevant to the type of attribute variable, i.e., continuous or disperse, ${}^u_j(M_i)$, which can be computed out by the following formulas:

If $s^u(M_i)$ is closer to 1, then the module case is more similar to the target module, i.e., the module case can satisfy the customer requirement better. When $s^u(M_i)$ is compared with , which denotes some degree of satisfaction index, the candidate modules which are restricted to $s^u(M_i)$ can be searched out. If the number of the candidate modules is z_i, then the set of candidate modules on M_i is $\{M_i^1, M_i^2, \ldots, M_i^{z_i}\}$.

Step 4. According to the above three steps, after computing the similarity degree of each module case in different GM and target modules, the set of candidate modules of each GM is $\{M_1^1, M_1^2, \ldots, M_1^{z_1}\}, \{M_2^1, M_2^2, \ldots, M_2^{z_2}\}, \ldots, \{M_m^1, M_m^2, \ldots, M_m^{z_m}\}$.

For the modular structure of a product family we can find out the module combination subjected to the above constraints from down to top in the modular structure of that product family, as illustrated in Fig. 2.2. If the set $\{M_b^1, M_b^2, \ldots, M_b^{z_b}\}$ is the combination of modules derived from the set $\{M_d^1, M_d^2, \cdots, M_d^{z_d}\}$ and $\{M_e^1, M_e^2, \ldots, M_e^{z_e}\}$, then we add the cost $\{MC_d^1, MC_d^2, \ldots, MC_d^{z_d}\}$ and $\{MC_e^1, MC_e^2, \ldots, MC_e^{z_e}\}$, e.g., the module M_b^1 can be obtained by combining the module M_d^1 and M_e^3, subjected to all the constraints, then $MC_b^1 = MC_d^1 + MC_e^3$ and we can get $\{MC_b^1, MC_b^2, \ldots, MC_b^{z_b}\}$. By the same reason, we will obtain the final modular product satisfying customer requirement. In the process of combination from down to up, the cost of modules are also accumulated up progressively to get the cost of final customized products.

Conclusion

In this chapter, a rapid cost estimation method of a MC product is proposed based on the modular product family model . Firstly, the modular product family model is established and the customer requirement is translated to the attribute variable of each generic module. Then, the similarity degree of the module case and the target module on the same module model can be calculated quantitatively to retrieve the similar module case, so that it is helpful to reduce the search time and promote efficiency. Finally, the cost structure of the different types of modules is analyzed, and different cost estimation methods are applied for different types of modules (basic module and customized module), so that the cost of the final customized product can be calculated quickly and accurately by accumulating the cost of modules in each level of the modular product family progressively.

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