The Development Strategy of Open architecture Products

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***Abstract*—The mass individualization paradigm based on open architecture products is regarded as a solution for increasing product variety. Open architecture products (OAPs) consist of a basic platform carrying on basic functions and several modules realizing personalized functions. The personalized modules are designed and developed with respect to the interface standards published by platform manufacturers. The benefits of OAPs include high level of individualization for the customers and opportunities for more companies to make innovative improvement to the products. The challenge is the reasonable product architecture design that determine the modules to be opened and maintain the open modules can be developed individually by different companies. This research focuses on the development strategy of OAPs that involve in product requirements and module identification issue. At first, the relationship between product requirements and product variety is analyzed, and the term of modular strategies is proposed to identify different kinds of product requirements. Then a modified quality function deployment (QFD) process along with a function decomposition and aggregation method are applied to identify modules with similar modular strategies. At last, an open architecture domestic refrigerator is used as an example to verify the effectiveness and effciency of the proposed method.**

***Index Terms*—open architecture products, mass individualization, module identification**

I. Introduction

A. Background

In recent years, manufacturing enterprises applies mass customization paradigm to produce various products in mass production. This approach has been widely applied in automobile industry like Volkswagen [1], and consumer products like Sony [2], HP [3].

Modular product architecture was widely applied in mass customization to produce various products by offering predefined combination of modules. However, as product variety rises and production volume decreases, mass customization is not able to meet the future needs any longer. Thus, the manufacturing paradigm in the future was discussed in [4]-[6]. Particularly, Koren described the future manufacturing paradigm as mass individualization in which customers or small companies were involved in the design of the individual products. In mass customization, customers could only choose from the predefined options given by the product family planning. While in mass individualization, customers can adapt the modules to their exact needs [5].

The concept of open architecture products (OAPs) was introduced by Koren as the key to mass individualization paradigm. An open architecture products was defined as one with a platform that allows the integration of modules from different sources in order to adapt product function exactly to the user's needs, while the involvement of customers or small companies added innovative design on the products [5]. Additionally, OAP brings the benefits to the society that many new small companies developing modules can be established and new jobs would be created.

The first iPhone model could be treated as one example of OAP in the IT field. Necessary hardware including chasing, communicating, displaying and software including the operation system were supplied as the product platform. Meanwhile, a series of development tools and application programming interface (API) were published for the medium or small companies to develop various applications (Apps). The consumer could apply Apps from various sources to meet their exact needs like office, photograph and entertainment. The success of iPhone proved the open architecture design to be a feasible and effective way.

Another example involved investigation of open architecture controller (OAC) for CNC machines in 1980s. This project proposed the concept that controller users would be able to add or swap modules from different vendor on the platform offered by the controller manufactured. Based on this concept, German researchers developed the OSACA (Open System Architecture for Controls within Automation system) platform [7]. However, the OAC is not utilized by industry today because that major industrial controller companies believe the modules having too many interaction with the

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core business of the platform. Therefore, the module identification of OAP should take the technology system of the products into consideration.

The success of iPhone and failure of OAC have both pointed out a fact that the OAP design should be based on the reasonable product architecture design, which concerns the definition of product modules and whether the module should be hold in the platform or opened for the developers. This issue is regarded as the development strategy of OAP.

B. *Literature Review*

Modular design is the basis of both modular products for mass customization and OAP for mass individualization. However, the modular design for mass customization usually focused on issues within companies like cost and development time. Thus, modular design methods are often applied to draw the conflict between commonality and variety via two approaches named ‘bottom-up’ approach and ‘top-down’ approach, respectively.

Traditional modular design mostly applied the ‘bottom-up’ approach to defining modules by summarizing and redesigning products that already exist. This method often result in components or assemblies being used across products to save cost. Huang and Kusiak used graph and matrix to represent the function relationship among components. This relationship was concluded into three modularity types as component-swapping, component-sharing and bus modularity [8]. A heuristic method and matrix decomposition method were applied to identify swappable or sharable modules among products [9], [10]. Gu et al. build the quantitative representation for components considering the lifecycle issues like disassembly, recycle and update. Then components having similar index were aggregated into a same module according to the simulated annealing algorithm [11]. Ericsson summarized the factors aff ecting module identification in product design, manufacturing and operating as 14 module drivers. The module function deployment (MFD) method was proposed to define components that have similar drivers as a module in a qualitative way [12], [13]. Based on Ericsson’s work, Kreng and Lee built the quantitative relationship between components and module drives. Optimization methods like integer programing and group generic algorithm were applied in the module identification process to make sure components in the same module having maximum similarity with the same drivers, and components in diff erent modules having minimum interaction in their drivers[14], [15]. The methods mentioned above aimed at reusing components or modules in the newly developed product models. However, reusing the current components or modules would result in limit from the original design and increasing diffculty in creating new features.

Another way to identify modules was considered as the ‘top-down’ approach in which the function structure of products was analyzed and sub-functions were aggregated into modules. Stone introduced a heuristic method to identify function modules of product. The material flows, energy flows and signal flows among sub-functions were established to build the function structure of products. Then three heuristics including dominant flow, branching flow and conversion flow were proposed to identify modules according to the flow patterns of sub-functions [16]. Based on Stone’s work, the function structure was conversed into generalized directed graph and generalized adjacent matrix. The flow heuristics were described as three principles, while modules satisfied the principles were identified as modules with an optimization algorithm [17].

The methods mentioned above could be applied in the early stage of product design to maintain the modules’ functional independence. However, the factors affecting open architecture design were not considered in these methods. This would result in modules that are nether suitable to build the platform nor open for the developers. In other words, the modular design of OAP should give function modules the instruction of whether they are going to be kept in the platform or open for the developers. Therefore, the development strategy of OAP proposed in this paper is mainly concerning with the module identification process. The product requirements affecting product variety and the concept of modular strategies for OAP are discussed at first in section 2; then a module identifying method for the modular strategies including a modified QFD analysis and function analysis process is illustrated at section 3; finally, a case study of OAP development for a household refrigerator is discussed in Section 4.

II. Product Requirements and Modular Strategies for OAPs

A. *Product Requirements and Product Variety*

OAP is supposed to be the solution for the dramatically increased product variety in recent times and future. Generally speaking, there are two categories of product variety: variety among different market segments, and generations over time. The domestic refrigerator is taken as an example as Fig. 1. At a certain time there were product models with different structure types, capacity and out looking along with different price, resulting in variety among different market segments as Fig. 1 (a). Other characteristics of domestic refrigerators follow the same rule. On the other hand, as time passed new features were added or performance were improved to attract customers and win the competition with opponents on similar products, resulting in generations over time. As illustrated in Fig. 1 (b), the three door refrigerator model were improved in the control method in generation 2, and a new feature of vacuum preservation was added on generation 3 to update the preservation capability.

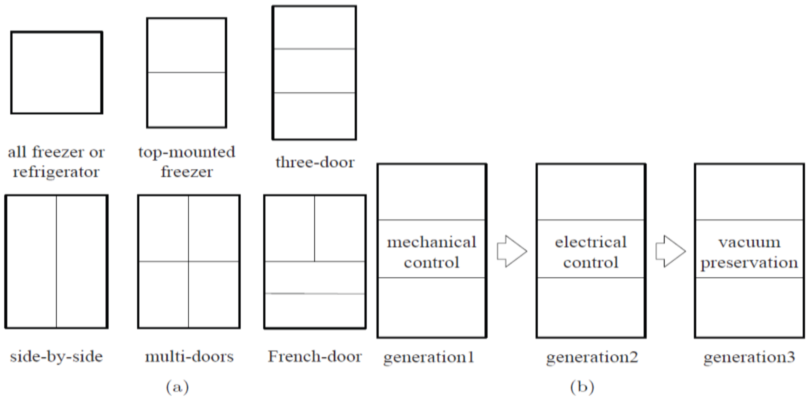

Figure 1. Product variety of domestic refrigerator.

As many literatures concluded, the characteristic of product requirements is the reason of product variety. Thus, the product requirements also can be classified into two categories with respect to the product variety: customer requirements and technical requirements. Customer requirements (CRs) are the requirements proposed by customers for the desired features or specifications. For example, the CRs of domestic refrigerator could be the desired feature combination, structure type, capacity, and out looking. One important characteristic of CRs is that different customers or market segments would have various preferences for the product features and specifications. The variety of CRs is often caused by the customers' using scenario, personal preference, judgment and buying ability. For instance, the small size all refrigerator might be popular in the school dormitory because of its small space and low price, while the French-door model might be useful for big families especially those with high demand of freezing (seeing Fig. 2a). In order to win market share, manufacturers developed various products to satisfy the CRs, resulting in product variety among customers or market segments. Technical requirements (TRs) are requirements that customer will not mention, but driven by the technology evolution like material technology or manufacturing techniques. New generation of products would be created by TRs with new features or promoted performance. For examples, the electrical controlling technology was applied on three door refrigerators to achieve better preservation capability by higher temperature precision, and the vacuum preservation technology was developed to add a new feature to preserve fresh food like salmon (seeing Fig. 2b).Although new products driven by TRs may lead to big success like the iPhone model, finding TRs and changing them into technical solutions might need a lot of innovative work and strong R&D ability.

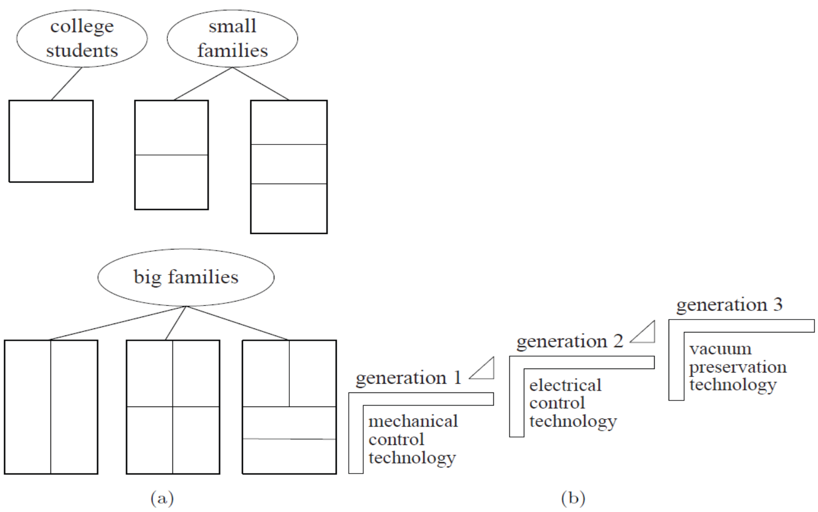

Figure 2. The relationship between product requirements and product variety

B. *Modular Strategies for OAP Development*

The purpose of opening product architecture is to solve product variety problems by dividing the product architecture into modules that some are defined as platforms，which manufactured by big companies, and the others are opened for the developers. Thus, the product modules should be defined to reflect the influence of product requirements on the product variety, that is, have specific strategies. The concept of modular strategies is proposed to give the modules clear instruction whether they are to satisfy common requirements, various CRs or TRs. Therefore, three kinds of strategies are concluded in this paper named standardization strategy, customization strategy and technology evolution strategy. These strategies are illustrated as Table I.

TABLE I. ILLUSTRATION OF MODULAR STRATEGIES

type	Description
Standardization	Decrease cost and shorten leading time by reusing modules across products
Customization	Meet requirements of different customers by combining modules
Technical evolution	Drive customer needs by updating modules

Modules with different strategies have different designing, manufacturing and management manners. For instance, standardization modules are suitable for mass production; customization modules have to hear the voice of customers and to be facilitated with flexible manufacturing system (FMS); technology evolution modules needs deep research into fundamental technology. Additionally, the product opening plan can be made according to the modular strategies: standardization modules are suitable to be hold in the platform to increase component commonality; customization modules are suitable to be opened for the developers to satisfy the personalized CRs; technology evolution modules involved with the core technology of platform manufacturers should be kept in the platform, while those not concerned by the platform manufacturer could be opened for the developers to have more innovative design work. The relationship between modular strategies and the opening plan of OAP can be seen as Fig. 3.

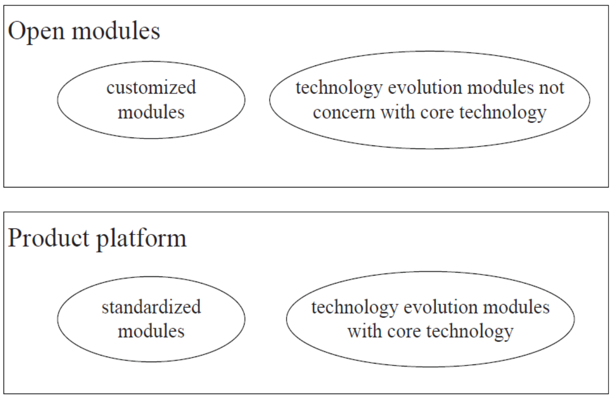

Figure 3. The relationship between modular strategies and OAP.

According to the modular strategies for OAP, the product opening plan can be made by aggregating standardization modules and technical evolution modules with core technology into the platforms and opening the rest modules. Therefore, the main task of open architecture design is to participate the product functions into modules with three kinds of modular strategies.

III. IDENTIFYING MODULES FOR MODULAR STRATEGIES

Based on the concept of modular strategies introduced in Section 2, modules with modular strategies should be identified in the early stage of OAP development. In this paper, a modified QFD method is applied to build the relationship between product requirements and product functions at first. Based on the QFD analysis, the strategy type of sub-functions are defined, then sub-functions with similar strategies are aggregated into modules.

A. QFD Analysis for Modular Strategies

QFD is a useful and important approach that can translate product requirements into product functions and engineering characteristics. However, the traditional QFD approach didn't take the product requirement variety into consideration. Therefore, a QFD analysis for modular strategies considering CRs distribution and TRs evolution is proposed in this paper. There are three steps of the QFD analysis for modular strategies as follows:

STEP1 Identifying sub-functions satisfying customization strategy if they meet the CRs having personalized characteristic.

STEP2 Identifying sub-functions satisfying technology evolution strategy if they meet the TRs having evolution characteristic.

STEP3 Identifying sub-functions satisfying standardization strategy if they don't meet the various requirements in the former two steps.

These steps are illustrated in detail.

Defining sub-functions with customization strategy: At first, the original CRs are generated by investigating customers and expressed as: $cr = (cr_1, cr_2, \cdots, cr_m)$, while the respective weights can be defined as: $\omega = (\omega_1, \omega_2, \cdots, \omega_m)$, where cr_i represents the ith customer requirement, ω represents the weight of the ith requirement with integral numbers from 1 to 5. Larger number indicates more importance of the requirements. Specially, $w = 0$ means no needs for the ith customer requirement. Thus, the CRs can be expressed as Table II.

TABLE II. ORIGINAL CRS OF DIFFERENT CUSTOMERS.

CRs	Weights			
	Customer 1	Customer 2	⋯	Customer m
cr_1	ω_{11}	ω_{12}	⋯	ω_{1m}
cr_2	ω_{21}	ω_{22}	⋯	ω_{2m}
⋮	⋮	⋮	⋮	⋮
cr_n	ω_{n1}	ω_{n2}	⋯	ω_{nm}

The original CRs are expressed in a rather ambiguous and fuzzy way. They should be translated into product functions and specifications. For this purpose, the product's main function should be separated into several sub-functions according to the CRs. Methods like function analysis system technique (FAST), Function means tree can be applied in the function decomposition process. After that, the product functions and sub-functions are arranged in a hierarchic form shown in Fig. 4, where F0 represents the product's main function, F1 and F2 represent the sub-functions of F0, F1.1, F1.2 andF1.3 represent the sub-functions of F1 and so on.

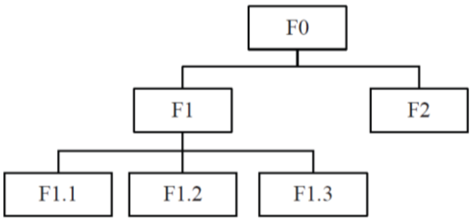

Figure 4. Hierarchic form of product functions and sub-functions.

As illustrated in Table 2, the CRs of one individual customer or market segment can be represented by the respective CRs' weight vector. Different weight vectors would result in different combination of sub-functions and different values of engineering characteristics. The influence of various CRs on the functional combination is the deciding factor whether one specific sub-function should be contained in the product or not. For example, if one customer for domestic refrigerator has requirements of preserving fresh food like salmon and is not sensitive to price, the function of vacuum preservation seems to be the proper option. Thus, a conversion can be made from CRs weight vector ω to a vector *x* of $0-1$ integer as:

$$\omega \rightarrow x = (x_1, x_2, \ldots, x_n) \tag{1}$$

where $x_i = 1$ means the function F_i is included in the product and vice versa. It means the requirements of an individual customer or market segment can be satisfied by a specific functional combination. The conversion can be operated by techniques like Rule Based Reasoning (RBR) and so on. Based on the result of *x*, the sub-functions having value of both 0 and 1 among different customers are thought as satisfying the customization strategy, because the sub-functions are only needed by some of the customers.

Furthermore, for the sub-functions whose value all are 1, the target values of their engineering characteristics need to be considered. These engineering characteristics can be defined as $s = (s_1, s_2, \cdots, s_m)$ where s_i represents the i_{th} engineering characteristic. The target value of these engineering characteristics can be determined by analyzing the related customer requirements and their weights. It means the target values of s_i can be determined by a function of ω as follows:

$$s_i = \Phi(\omega) \tag{2}$$

where Φ is the conversion function from weight ω to the target value of s_i. The conversion can be operated by methods like house of quality (HOQ, seeing Fig. 5), RBR, or benchmarking. For example, if a customer has a strong desire (number of 4) to have large store space, a relatively high value should be assigned to the engineering characteristic 'capacity'. Additionally, for the j_{th} customer

$$s_i^{(j)} = \Phi(\omega^{(j)}) \tag{3}$$

where $\omega^{(j)}$ represents the weight vector of the j_{th} customer, $s_i^{(j)}$ represents the target value of s for the j_{th} customer. Then, the target value of s can be obtained for all the customers or market segments one by one with Eqs. (3). After that, the distribution model of *s* among customers or market segments can be built by statistics methods. Particularly, the distribution model among market segments are taken into consideration in this paper. The mean value of specification *s* in the market segment p_j is defined as j, and the standard deviation in the whole market place is defined as σ_{total}. The conclusion can be drawn that s_i is proper to have a unique value when the CRs seem to be the same, where σ_{total} has a relative low value. Otherwise, varied value would be set for s_i when the customers have various requirements among market segments, where σ_{total} has a relative high value and $\mu_j \neq \mu_k$ when $j \neq k$. As a result, the value of σ_{total} can be treated as a deciding factor to the variety of s_i and CRs

CRs & weights		Engineering characteristics s_1	s_2	⋮	s_n
cr_1	w_1		3	⋮	
cr_2	w_2	9		⋮	3
…	…	…	…	⋱	…
cr_m	w_m	1		⋮	1

Figure 5. The house of quality in conversion function from ω to si.

For example, the engineering characteristic 'capacity' of domestic refrigerator was studied in a market with customers in different ages. Three target market segments were defined according to the age as {p1 : under 30; p2 : 30 to 50; p3 : beyond 50}.Assuming the engineering characteristic has property of normal distribution, the distribution model of 'capacity' can be built as Fig. 6.The calculation result shows $\sigma_{total} = 93$ which seems to be a high value, implying there would be only a part of customers feel satisfied with the product if a unique value of capacity is assigned. On the contrary, the customers would feel more satisfied if mean value m_1, m_2, m_3 of each market segment are assigned as three target values. As a result, the sub-functions carrying out 'capacity' are supposed to satisfy the customization strategy.

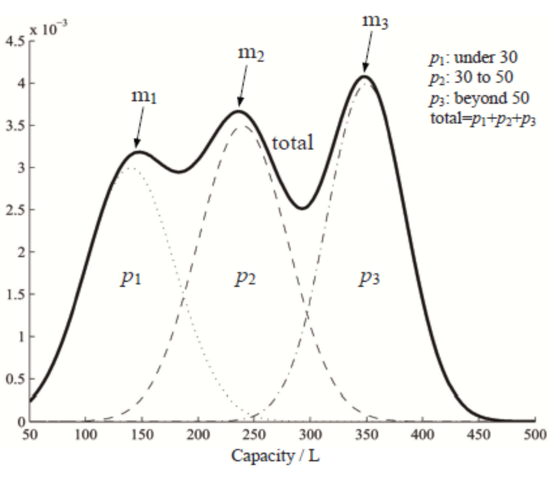

Figure 6. The distribution model of 'capacity'.

Defining sub-functions with technical evolution strategy: At first, related technology information should be collected to build TRs as {O, P, L},where O represents product information from opponent companies, P represents rules and politics, L represents related patents, literatures and research reports.

Then the evolution pattern of engineering characteristic s_i were studied to form the evolution model $s_i(t)$. $s_i(t)$ is the curve of s_i against time and can be obtained by tracing the historical products. Based on the result of $s_i(t)$, the conclusion can be drawn that s_i is not affected by technical requirement if $s_i(t)$ keep stable; otherwise s_i is affected by TRs if $s_i(t)$ changes with time. In order to study the property of $s_i(t)$ quantitatively, define μ (the mean value in the time period [a,b]) to evaluate the change level of s_i, ξ (the integral of absolute deviation divided by mean value) to evaluate the evolution potential of s_i

$$\mu = \frac{1}{t_b - t_a}\int_a^b s_i(t)dt \tag{4}$$

$$\xi = \frac{\int_a^b |s_i(t) - \mu_s| dt}{\mu_s} \tag{5}$$

For example, the engineering characteristic 'energy consumption' of domestic refrigerator is focus of the government and society. With the encouragement of laws and politics, new models were developed with lower energy consumption year by year. The energy consumption of a 250L three door refrigerator model in Chinese markets in five years was recorded as Fig. 7.The calculation result shows a large ξ = 0.78, implying 'energy consumption' is affected by TRs like politics and technology evolution in refrigeration aspect. So the sub-functions carrying 'energy consumption' like control and refrigeration are supposed to satisfy the technical evolution strategy.

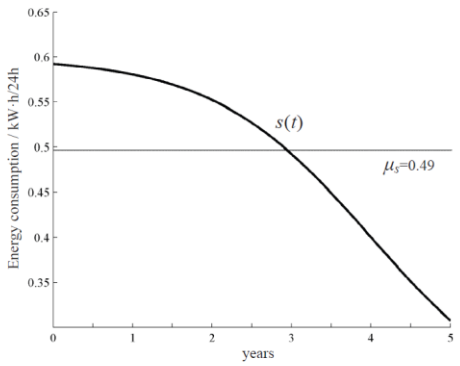

Figure 7. The evolution model of 'energy consumption'.

Defining sub-functions with standardization strategy: Sub-functions without property of the previous two sections satisfy the standardization strategy. For instance, the sub-function 'insulating heat' of domestic refrigerator has no difference when the CRs change, and are not the development focus of refrigerator companies since the technology has been rather mature in the current years. So the 'insulating heat' can be defined as satisfying the standardization strategy.

B. Identifying Function Modules for Modular Strategies.

There are traditional methods like flow heuristics (Stone et al. 2000) to identify function modules under function structures. But for OAP development, the modular strategies of sub-functions must be taken into consideration as well, because more than one kind of strategies carried on one module will result in conflict and make negative effect on product opening. Therefore, the module identification process for modular strategies is comprised of two steps: decomposition of function into sub-functions with unique strategy, and aggregation of sub-functions into function modules with same strategy types.

In the step of decomposition, some sub-functions may contain more than one kind of strategies. These sub-functions need to be separated into smaller and more specific sub-functions until these sub-functions have unique strategy types. For instance, the sub-function 'store food' of domestic refrigerator satisfies the standardization strategy to hold bodies. At the same time, it contains the customization strategy for ability to store different kind of food. Consequently, it needs to be separated into two sub-functions as 'hold bodies' to satisfy the standardization strategy and 'contain food' to satisfy the customization strategy.

In the step of aggregation, the modular strategies among sub-functions are taken into consideration, and cannot be affected by the physical structure already exist. For example, the domestic refrigerator has a sub-function of 'open/close doors' satisfying the standardization strategy. At the same time the sub-function 'beautify appearance' satisfies the customization strategy. In current design these two sub-functions are integrated in one same physical assembly that conjoined by vacuum foaming which cannot be separated once fabricated. Therefore, once the 'beautify appearance' module as to be changed with customers' preference, the 'open/close doors' module should be adjusted to fit the changes. It will result in longer development time and new kinds of components. The reasonable design is making the two sub-functions into modules of their own, and connected by standard interface, as shown in Fig. 8.

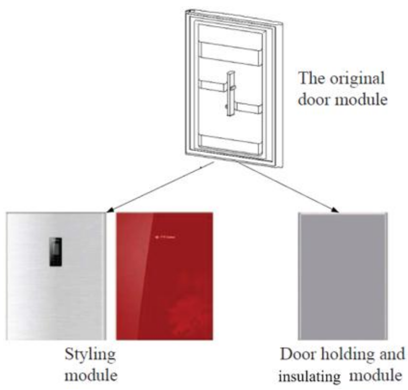

Figure 8. Separation of the refrigerator door.

As a result, modules with modular strategies can be identified by the proposed method with QFD analysis and function module identification process. Based on the module definition result, the product opening plan can be made to solve the product variety problem by aggregating standardized modules and technical evolution modules with core technology into platforms and opening the rest modules.

IV. Case Study: The Development of Open Architecture Domestic Refrigerator

Domestic refrigerators are one of the consumer electrics playing an important role in people's daily life. As the personalized requirements increase in recent years, refrigerators were developed into different features and specifications to meet various requirements. For instance, in China there are a lot of refrigerator products, varying in capacity, structure types, and additional features like vacuum preservation boxes and ice makers. However, the refrigerators in current markets only offer several options for customers to choose and couldn't be customized according to the personalized requirements. Therefore, the development of open architecture refrigerator (OAR) has significant meaning. The case study of OAR development is mainly comprise of a module identification process with respect to modular strategies.

A. QFD Analysis for Modular Strategies

Defining sub-functions with customization strategy: The OAR is supposed to meet the requirements of customers that have personalized needs for food preservation. An investigation can be made to the customers by means of talks, questionnaires, telephones and so on. Then the importance of these requirements for every customer was expressed in number from 0 to 5, as shown in Table III. In particular, customer 1~3 are three of the investigated customers representing a big family, an old couple family and a young couple family, respectively.

TABLE III. CRs and Their Weights of Different Customers of Refrigerator

CRs	Weights		
	Customer 1	Customer 2	Customer 3
Big volume capability	5	0	3
Good ability to store vegetable and fruit	4	5	3
Store fresh food	2	0	5
Saving energy	5	5	4
Good freeze capability	4	0	2
Low price	2	5	3
Low noise	3	5	4
Easy to use	4	5	4
Avoid wrong action	0	0	4
Saving energy when on vacation	0	0	4
Good looking	2	2	4
Durability	4	5	4

Based on the CRs, the function of the domestic refrigerator can be decomposed hierarchically as Fig. 9. Finally, the functions of the refrigerator can be modeled as {F1.1, F1.2, F1.3, F2.1,F2.2, F2.3, F2.4, F3.1, F3.2, F4, F5, F6}. Based on Table 3, the conversion can be made from CRs weights to the function combination by Eqs. 1. For example, customer 1 and customer 2 have relatively strong requirements for storing vegetable and fruit because the weights for 'good ability to store vegetable and fruit' are 4 and5 respectively. Besides, customer is more sensitive to price than customer because of larger weight on 'low price'. At the same time, 'increase humidity' (F4) is helpful to keep vegetable and fruit fresh. Thus, F4 is more suitable for customer 2 than the other two customers. Similarly, 'decrease pressure' (F5) and 'Kill bacterium' (F6) can be offered to customer 3 who is fond of fresh food. Finally, F4, F5 and F6 are supposed to satisfy the customization strategy. For the sub-functions that are required by all the customers, the related engineering characteristics are list as: {s_1: energy consumption, s_2: energy effciency, s_3: capacity, s_4 : way of control, s_5 : style, s_6: service lifetime, s_7: noise, s_8: insulating capability}. Then the distribution model can be built by Eqs. 3. The σ_{total} of the distribution can be derived by statistics methods as shown in Fig. 6. The engineering characteristic likes that have high value of σ_{total} is considered to meet the personalized requirements. Then the sub-functions realizing these engineering characteristics such as 'offer space'(F1.3) are supposed to satisfy the customization strategy.

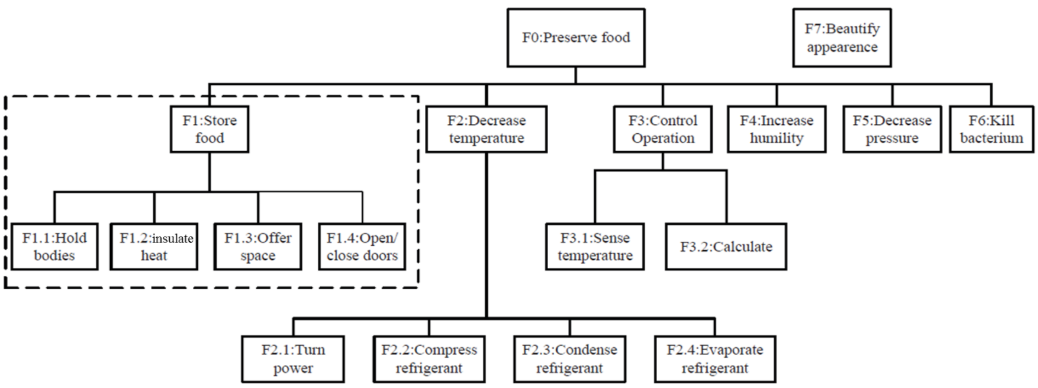

Figure 9. The function decomposition of the domestic refrigerator.

Defining sub-functions with technical evolution strategy: The TRs can be built as {O, P, L}, where O represents the products information of opponents. P includes rules and politics like RoHS and low carbon policy. L represents the related literature and patents like system matching, preservation technology, control technology etc.

Based on the TRs, the values of engineering characteristics are recorded and the evolution model is built as Fig. 7. Then the ξ can be calculated by Eqs. 4 and Eqs.5. The ξ of s has a high value of 0.78, meaning the sub-functions realizing s_1 such as 'compress refrigerant' (F2.2) and 'evaporate refrigerant' (F2.4) satisfy the technology evolution strategy.

Defining sub-functions with standardization strategy: The sub-functions having no distribution and evolution characteristics are thought to satisfy the standardization strategy like 'hold bodies' (F1.1), 'insulate heat' (F1.2) and so on. In summary, the sub-functions and their strategy type are listed in Table IV.

TABLE IV. THE STRATEGY TYPE LIST OF SUB-FUNCTIONS

Sub-functions	engineering characteristics	Strategy type
F1.1, F1.4	s6	standardization
F1.2	s8	standardization
F1.3	s3	customization
F2.1, F2.2, F2.3, F2.4	s1, s2, s7	technical evolution
F3.1, F3.2	s4	technical evolution
F4	-	customization
F5	-	customization
F6	-	customization
F7	s5	customization

B. Identifying Function Modules with Modular Strategies for OAR

In the decomposition process, the sub-functions need to be divided if more than one kind of strategies are carried. For example, sub-function store food (F1) is divided into more specific sub-functions as 'hold bodies' (F1.1), 'insulate heat' (F1.2), 'offer space'(F1.3)and 'open/close doors' (F1.4) as shown in Fig. 9.

Then the sub-functions can be aggregated into modules according to Stone's heuristics (a simple example can be seen as Fig. 10. The function modules identified by flow heuristics are detected to find if two or more modular strategies are carried in one module. If so, the function module should be separated into several smaller modules. It needs to be noted that the module identification result according to module strategies would be different to the structure already exist. For example, F1.1 and F1.3 are contained in a same module as 'store module' by the heuristic method, while they satisfy the standardization strategy and customization strategy respectively. Therefore, the 'store module' should be separated into two modules as 'hold bodies module' and 'offer space module' (shown in Fig. 11). The former can be made to realize the basic function in a common way, and the latter can be made to different styles to meet the customized requirements for capacity. Another example is the 'door module' of the refrigerator, which carries the sub-functions of 'open/close doors' (F1.4) and 'beautify appearance' (F7), while the two sub-functions have conflict in strategies. So two modules are designed to carry the sub-functions separately as shown in Fig. 8.

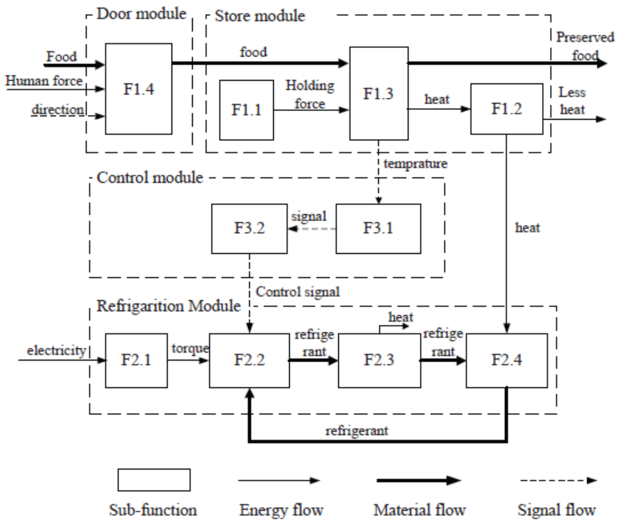

Figure 10. Aggregate sub-functions into modules by heuristics.

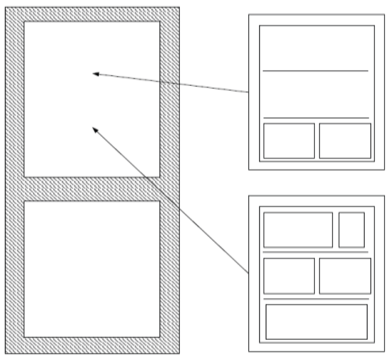

Figure 11. Separation of the store module.

Finally, modules of OAR are defined as shown in Table V. Based on the module identification result, the platform of OAR can be determined as modules including refrigeration module, control module and holding and insulting module, while modules including containing module, increasing humility module, killing bacterium module and styling modules can be opened for the developers to design customized or innovative features. Therefore, the product variety problem of the domestic refrigerator can be solved.

TABLE V. MODULE IDENTIFICATION FOR OAR

modules	Included sub-functions	Strategy types
Refrigeration module	F2.1, F2.2, F2.3, F2.4	Technical evolution
Holding and insulting module	F1.1, F1.2	Standardization
Containing module	F1.3	Customization
Door holding and insulting module	F1.4	Standardization
Control module	F3.1, F3.2	Technical evolution
Increasing humility module	F4	Customization
Decreasing pressure module	F5	Customization
Killing bacterium module	F6	Customization
Styling module	F7	Customization

V. CONCLUSION

This paper has presented the development strategy for open architecture products which are the key to the mass individualization paradigm. At first product requirements are proven to have significant influence on product variety, and the concept of modular strategies is introduced to separate the common parts and varied parts of products to support the opening plan decision. In order to identifying modules with modular strategies, a modified QFD process is proposed to study the distribution and evolution of engineering characteristics and define the strategy types of sub-functions. Then a function decomposition and aggregation method is used to identify modules with similar modular strategies. Finally, the product is separated into several modules carrying different strategies, and the opening plan can be made based on the strategy type of modules. In summary, the product variety problem is solved by the OAPs development strategy based on modular strategies. The effectiveness and effciency of the proposed method is verified by a case study of an open architecture domestic refrigerator.

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