Research on Fuzzy Hierarchy Optimization Model of Product Family Parameters Based on Flexible Design of Clothing

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Abstract. In this paper, by means of summarizing the current situation of product family design, methods of product family design based on the common platform is discussed. The concept of the fuzzy hierarchical optimization model which is the main model type is advanced. Further, this method educes product family design methodology under multipurpose constraint environment, which is used to achieve response to customer requirements. Moreover, this method is al so used to integrally considering the comparability and diversity so that the application can lend itself to attain the flexibility of product family design and to support the dynamic customer requirements.

1. Introduction
The term "mass customization" first appeared in the 1970 book of the prophet Alvin Toffler’s book The Impact of the Future. In 1993, Joseph Pine II gave a complete description of the concept of mass customization [2]. But it has only been paid attention to by people in recent years. Mass customization was originally applied to the mechanical manufacturing industry and was gradually extended to other industries. The successful implementation of Levi Strauss & Co.’s mass-customized brand “Personal Pair” jeans proved that the production method is equally applicable to the apparel manufacturing industry. Garment mass customization is an advanced garment enterprise production and management model that integrates garment enterprises, customers, suppliers and the environment, and makes full use of the latest research results of human beings in various technical fields [3]. One of its core ideas is to require apparel companies to produce personalized clothing at times and costs similar to mass production. First of all, it is a philosophy that guides garment enterprises to participate in market competition. It requires garment enterprises to consider the relationship with customers from the perspective of long-term interests. "Customer satisfaction" is one of the highest pursuit goals, attracting and "permanently" retaining customers. Secondly, it is a way for garment enterprises to organize and manage production. It requires enterprises to provide customers with any variety and quantity of clothing by speed, cost and quality similar to mass production through rational allocation of resources and optimization of operation process. Third, it is a guideline for designers to design customized products, requiring designers to fully consider the individualized variants of the clothing in the design process [4].

With the increasingly fierce market competition, the global market has shifted from the seller's market to the buyer's market. Consumer demand tends to be diversified, flexible and personalized. The target market of products is becoming more and more fine. The focus of competition among enterprises
is not only how to satisfy the maximum satisfaction. Consumer demand is also focused on how to shorten product development cycles, improve product quality and reduce product cost. In order to improve the competitiveness of products, manufacturers are looking for effective strategies to reduce product costs and development cycles. Mass Customization is generated in this context. It is a production model that based on the individualization of each customer and provides customized products and services with low cost and high efficiency in mass production [1].

By analysing the existing user requirements and combining the predicted requirements, the product family design extracts the deformation parameters according to the customized method to be used, and designs a family of products to form a deformable product model, which provides a theoretical basis for the rapid design of customized products. The essence of product family design is to identify and exploit the commonalities and similarities in design and manufacturing. This similarity includes the similarities between user needs and market competition to construct a product family architecture. A reasonable product family architecture not only facilitates the communication between the marketing department and the user, determines the configuration relationship of each module, but also reflects the optimal configuration of the manufacturing process, thereby reducing the cost loss caused by the variation. In this process, because of the necessity to analyze the user's needs, and consider the relationship between different products in the design, it must reflect the constraints of the manufacturing process. Therefore, how to obtain a public core platform becomes the key to the development of product family architecture.

2. PRODUCT FAMILY DESIGN METHOD BASED ON MAPPING TECHNOLOGY

An important idea of mass customization design is to realize the transformation from reactive to pre-determined design ideas. To this end, it is necessary to meet the requirements by planning and designing a family of products. The product range includes product lines over time and product lines at a certain point in time [6]. In the process of designing a product family, it is necessary to respond to the dynamic changes in user requirements so that the designed product family is highly adaptable to changing needs. Another feature of the product family design is that it is designed under a number of target constraints.

The dynamic changes in user demand mainly include changes over time and changes at a certain point in time, which will be passed downstream and affect the composition and structure of the product. The product family design to achieve user needs and the mapping between user requirements, product parameters and product functions need to be carried out in two steps. The first step is to achieve a mapping between user requirements and product parameters, and the second step is to implement product parameters. And mapping of product features.

The relationship between user requirements and product parameters is generally vague at the beginning of the design. The mapping between the two is the core and foundation of mass customization. The final planned product family is to plan the design as a whole based on all the above changes. Therefore, the result of mapping user requirements and product parameters is to form a product parameter for the entire product family rather than for a single product. set. A reasonable analysis of the collection, through the allocation of indicators to divide the changes of each product member in different periods and the same period, can achieve the planning of the entire product family.

The change in demand causes a change in the value of the corresponding product parameter, and the degree of this change is different for different user requirements, and the change of the product parameter brings about the change of the specific component selection. The two levels of association mapping realize the impact of changing user requirements on the final parameters of a functional model of the product family, and finally obtain the product family component module relative to the series of products (series products at different time points and over time) The overall requirements of the product family can be designed on top of this.

3. MATHEMATICAL PLANNING METHODS FOR PRODUCT DESIGN

3.1. Solution definition
A typical traditional optimization method is to find the optimal value to express the performance index. A performance indicator is given below:

\[ p = f(d) \]

Get the minimum value by finding \( d^* \) and get:

\[ f(d^*) = \inf \{ f(d) \mid d \in Z \} \]

This result is the minimum solution

\[ f(d^*) = \min \{ f(d) \} \]

This method represents all the optimization problem solving formulas.

3.2. Basic concepts of optimization

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Constraint: A constraint is a performance evaluation metric and a target value pair used to constrain the final solution to exhibit additional characteristics beyond the set \( Z \). Local constraints: Calling such a constraint an inequality constraint is represented by \( g_j \). For the convenience of calculation, the upper limit of these expressions is usually converted to 0.

\[ g_j(x) \leq 0 \]  

Equality constraint: This type of constraint condition defines that some design variables are related at the same time, and \( h_j \) is used to represent equality constraints. Similarly, the equality constraint \( h_j \) is deformed to obtain:

\[ h_j(x) = 0 \]

3.3. Objective function

Beyond the constraint condition, the required performance metric is to identify an objective function that is a function that is managed to minimize. Definition: The objective function refers to determining which structure is optimized for the other performance index \( f \) by minimizing \( f \) in the \( Z \) zone.

3.4. Standard form

When the product performance index is converted into \( g_j \) and \( h_j \) constraints and a single index is selected as the objective function, the expression of the optimization problem is formed [7]:

\[
\begin{align*}
\text{Minimize} & \quad f(\vec{d}) \\
\text{Obey} & \quad \vec{g}(\vec{d}) \leq 0 \\
& \quad \vec{h}(\vec{d}) = 0
\end{align*}
\]

Here \((\vec{d}) \in Z = R^n\), all performance indicators are real values. Each point \( \vec{s} \in Z \) that satisfies the constraint of (3) is a feasible point, and all such points constitute a feasible space \( S \). The expression of this optimization problem forms the standard form of nonlinear programming problems.

4. OPTIMIZATION MODEL OF PRODUCT FAMILY PARAMETER DESIGN

According to the idea of product family design, the design variables are divided into platform variables and differentiated variables. Here, the platform variable is assumed to be \( x \), and the differentiated variable of each personalized product is \( y_i \). For all products, the value of the platform variable \( x \) is the same, and the non-platform variable \( y_i \) has different values depending on the product, that is to say, all products have their own differentiated variable \( y_i \), and the product's direct differential variable is none. Mutually affected, but both are affected by the platform variable \( x \).
Product design plays an important role as a link between the market and production. On the one hand, the products designed must meet the needs of the market. On the other hand, the products produced must be adapted to the actual production capacity of the company and can be lower. Cost to produce. Therefore, the optimized design of the product family should realize the integration of market, design and manufacturing, and achieve a good connection between the three ones [8]. In this paper, a two-tier planning with fuzzy coefficients (objective function and constraint condition expression with fuzzy coefficients) is applied to study the optimization model of product family parameter design. The specific model is as follows:

$$\begin{align*}
\min \ F(x, y) \\
\text{s.t.} \ H(x) \leq 0 \\
y(x) = (y^1(x), y^2(x), \ldots, y^N(x)) \\
y^i(x) = \arg \min f_i(x, y^i) \\
\text{s.t.} \ g^i(x, y^i) \leq 0 \quad i = 1, 2, \ldots, N
\end{align*}$$ (4)

The upper objective function is $F(x, y)$, the decision variable is the platform variable $x$, the lower optimization target is $f_i(x, y^i)$, and the decision variable is the differential variable $y^i$.

In the fuzzy coefficient planning, the following two points are pointed out:

- For any fixed membership degree, the cut off of an arbitrary fuzzy number is a closed interval (when $\lambda=0$, the cut set of $\lambda$ with $\hat{e}$ is defined as the support set of the fuzzy number), that is $\hat{e}(\lambda) = [e^L(\lambda), e^U(\lambda)],$ the real number is $\hat{e}(\lambda) = [e^L(\lambda), e^U(\lambda)]$.

- A cut set for any fuzzy vector $\hat{e} = (\hat{e}_1, \hat{e}_2, \ldots, \hat{e}_n)$, the cut set of $\lambda$ with $\hat{e}$, which is $\hat{e}(\lambda) = [e^L_i(\lambda), e^U_i(\lambda)]$. If you take a value in each $[e^L_i(\lambda), e^U_i(\lambda)]$, you can get a vector $\hat{e}(\lambda) = (e_1(\lambda), e_2(\lambda), \ldots, e_n(\lambda))$. Because of $e_i(\lambda) \in [e^L_i(\lambda), e^U_i(\lambda)]$, get the expression $e(\lambda) \in [e^L(\lambda), e^U(\lambda)]$.

- It is not difficult to see from the model (4) that the upper objective function is a cost function related to the manufacturing capability of the enterprise, and is mapped to the platform function, and its optimization direction is minimized.

Consider the manufacturer's production function as $Q = f(x_1, x_2, \ldots, x_N)$, where $Q$ is the yield of the combination of inputs $(x_1, x_2, \ldots, x_N), x_i (i = 1, 2, \ldots, N)$ is the input amount of the $i$-th element. If the price of the $i$-th element is $p_i$, the manufacturer's production cost is $TC = p_1x_1 + p_2x_2 + \ldots + p_Nx_N = \sum_{i=1}^{N} p_i x_i$. For a given productivity $Q$, the manufacturer's cost minimization of production behavior can be expressed as: $\sum_{i=1}^{N} p_i x_i$

$$\begin{align*}
\min \{TC\} &= \min \sum_{i=1}^{N} p_i x_i \\
\text{s.t.} \ f(x_1, x_2, \ldots, x_N) = Q
\end{align*}$$ (5)

- The Lagrange function of the optimization problem (1) is:

$$L = \sum_{i=1}^{N} p_i x_i - \lambda \left( f(x_1, x_2, \ldots, x_N) - Q \right)$$

where Lagrange multiplier is $\lambda$. The first-order condition for minimizing vendor costs is:

$$\lambda \frac{\partial f}{\partial x_i} = p_i \quad (i = 1, 2, \ldots, N)$$

From formula (2) can get:

$$TC = p_1x_1 + p_2x_2 + \ldots + p_Nx_N = \sum_{i=1}^{N} p_i x_i = \lambda \sum_{i=1}^{N} \frac{\partial f}{\partial x_i} x_i$$

Known by the definition of the cost function:
\[ TC = C(Q) = \lambda \sum_{i=1}^{N} \frac{\partial f}{\partial x_i} x_i \]

In the formula, \( C(Q) \) is the cost function, and the Lagrange multiplier is the shadow price of \( Q \), that is, the increase per unit of production leads to an increase in the total cost. Therefore, the marginal cost for the optimal decision of the manufacturer is:

\[ \lambda = \frac{dTC}{dQ} = C'(Q) \]

For enterprises, even if the optimized design products have good performance, it is not feasible for the products produced by the company to be not profitable. Therefore, it is used as the upper-level decision-making problem of the two-tier planning and as a guide for the lower-level decision-making problems. The lower-level decision-making problem is the optimization problem of multiple slaves. The essence of the problem is the optimal design of the actual product, which embodies the optimization design of multiple products according to market demand. So, the objective function is \( f_i (x, y_i) \). Because the objective function would be the optimization of multiple product parameters of the \( i \)-th product, so it is mapped to the differentiation function, that is, the lower-level optimization problem in the formula (6) model:

\[
y^i (x) = \arg \min_{y} y_i (x, y_i) \quad \text{s.t.} \quad g_i (x, y_i) \leq 0 \\
i = 1, 2, ..., N
\]

5. EMPIRICAL RESEARCH

People have different requirements for clothing in different seasons. The frequency of people updating clothes is also increasing. They are required to wear different clothes at home, work, social, leisure, travel and other occasions, resulting in diversified market demand for clothing. Everyone chooses their favorite clothing according to their own personality, so that different seasons, different occasions and even each clothing have different needs due to different personality differences. Therefore, the clothing demand market is multivariate. There are no metrics for the individualized factors of clothing, and they cannot be quantitatively described and have ambiguity. Consumers’ individualized demand for clothing is also vague. People have basic goals in the minds of the various clothing needs, but the boundaries of the goals are not clear, and it is usually unclear what exactly they want [5].

![Figure 1. Customer Personalization Needs Schematic Diagram of Individualized clothing Design Decisions](figure1.png)

The final decision of the choice can be expressed by function (7):

![Diagram](figure1.png)
\[ Y_s = \sum_{i=1}^{i=n} \left( \xi_{i}^{\text{ind}} x_{j}^{\text{com}} + \xi_{im}^{\text{ind}} x_{jm}^{\text{com}} \right) + x_{ec} \]

\[ i = 1, 2, \ldots, n; j = m = 1, 2, \ldots, k \]

In function (7), \( i \) is the number of individualized demand items for the customer, \( j \) is the number of individualized design items for the garment, \( m \) is the number of fuzzy items designed for the individualized clothing, and \( Y_s \) is the final choice for the customer to purchase their own clothing and external factors.

For the individualized factorization of the customer, \( \xi_{i}^{\text{ind}} \) is the choice bias of the individualized design choice of the garment, \( x_{j}^{\text{com}} \) is the individualized design of the garment, \( \xi_{im}^{\text{ind}} \) is the choice bias of the different factors of the customer’s individual demand for the fuzzy factor of the garment, \( x_{jm}^{\text{com}} \) is the fuzzy factor in the design of the clothing personality, \( x_{ec} \) is various impact of external factors on the final decision of the customer. Because of the different \( \xi_{i}^{\text{ind}} \) and \( \xi_{im}^{\text{ind}} \) between different customers, the \( Y_s \) is also different. Under different moods and objective environments, the choice bias of each factor in the individual's personality changes the choice of clothing factors, and the \( Y_s \) may be uncertain due to the existence of uncertain variables.

Equation (7) reflects the ambiguity of the customer's selected target. The designer's suggestion is to increase the value of \( x_{ec} \) and \( Y_s \) in the neutralization. The result will reduce the ambiguity ratio and improve the decision-making speed of the customer. Converting a model with a fuzzy target into a lower-level objective function is the satisfaction function of the decision maker. For the enterprise, only the specific expression of the cost function is determined in the model, where the price coefficient and the disturbance variable meet the fuzzy number of a certain distribution. It can be operated to optimize the product family design and obtain satisfactory product parameter values. It can be imagined that the designer brand will be welcomed in the era of mass customization of clothing.

6. CONCLUSION

Differentiated variables \( y^j \) optimized for each product after determining the platform variable \( x \). Optimized design issues that meet the design requirements (based on market demand) reflect the integration of market (consumer demand) and design (personalized design capabilities). The upper-level decision-making problem reflects the manufacturing capabilities of the enterprise, while the lower-level decision-making issues reflect the market and design requirements, so that the two-tier decision-making problem realizes the integration of market, design, and manufacturing.

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