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Considering the Optimization Design of Product Function Requirements of Quantitative KANO Model

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ABSTRACT: Quality function deployment (QFD) is the important product planning method that achieve customer requirements to map product function requirements, using QFD to transform the important degree of customer requirements into the important degree of product function requirements, and fully considering the interaction relationship between product function requirements, using DEMATEL method to modify the important degree of initial product function requirements. KANO model is the important method to analyze the type of customer requirements, using the KANO model to analyze product function requirements and to quantify the relationship between product function requirements and customer satisfaction degree, so that to obtain the function equation of customer satisfaction degree. Making the maximize customer satisfaction degree as the optimization goal to establish nonlinear programming model, and to determine the final optimization solution of product function requirements. Instance is given to demonstrate the feasibility and effectiveness of the proposed method.

KEYWORDS: Product planning; Quality function deployment (qfd); Kano model; Dematel; Nonlinear programming.

INTRODUCTION

In the fierce market competition, in order to ensure a more powerful competitive advantage, the modern enterprise increasingly pay more attention to listen to "the voice of the customer" in the process of product development, customer satisfaction degree is the key to measure success or failure of product development. QFD (Quality Function Deployment) is the important method of product planning to realize customer demand drive, is "bridge" between "the voice of the customer" and "the voice of the engineering technical personnel". Fuzzy preference analysis firstly transforms the fuzzy importance degree of customer demand into the relative importance degree of customer requirements, by relationship matrix between the relative importance degree of customer demand and fuzzy association to calculate and obtain the fuzzy importance degree of engineering properties, and finally using the fuzzy preference analysis to obtain the relative important degree of engineering properties [1]. For fuzzy QFD problem, the paper respectively put forwards the rough set method to determine the correlation relationship and autocorrelation relationship, then to determine the initial importance degree of product engineering properties [2]. However, the above research does not take autocorrelation relationship of the engineering characteristics into full consideration. The paper full considers the interaction relationship between product function requirements, using DEMATEL method to modify the initial important degree of product function requirements obtained by QFD, so that to make the important degree of product function requirements more objective and accurate [3, 4].

KANO model is the important approach to analyze customer demand, which divides customer requirements into different types and considers the influence on different types of customer demand to customer satisfaction degree is different [5]. Considering the importance degree of product attributes defined by the customer, the paper expands the types of the customer requirements into eight classes [6]. In the process of KANO model data collection, considering the fuzzy factor and uncertainty factor existing in the actual [7] and putting forward to introduce the fuzzy theory into the KANO model, using fuzzy KANO questionnaire to modify the traditional KANO questionnaire and fully considering the fuzzy and uncertainty existing in the actual survey for the customer demands [8]. However, the focus of the above literature research more lies in the classification of the customer requirements and more makes the qualitative analysis as key, didn't propose specific solutions for how to quantify between customer requirements and customer satisfaction degree. For different types of customer needs to build the different function equation to represent the influence relationship that the implementation degree of the customer requirements to the customer satisfaction degree, and to quantify the relationship between customer demand and customer satisfaction degree [9]. This paper matches the relationship between different types of customer demand and customer satisfaction degree using the function equation [10], then to quantify customer satisfaction degree to make the problem analysis more accurate and reliable.

This paper firstly gets the initial importance degree of product function requirements through the product planning quality house, and then modifies the initial importance degree of the product function requirements using DEMATEL method to the more objective and accurate importance degree. Through the analysis of the survey questionnaire of product function requirements to build the fitting equation between excited demand, expected demand and basic demand and customer satisfaction degree, and to realize the quantification of customer satisfaction degree. Making the maximize customer satisfaction degree as the goal to establish the nonlinear programming model to optimize, then to get the best optimization design scheme of the product function requirements. Finally, instance is given to demonstrate the feasibility and effectiveness of the proposed method.

CALCULATION COMBINING THE IMPORTANT DEGREE OF THE DEMATEL AND QFD PRODUCT FUNCTION REQUIREMENTS

QFD is the important method to calculate the importance of product function requirements, in the past process of the construction of the QFD quality house, the importance degree of product function requirements only is obtained by calculating the correction relationship matrix between the importance degree of customer requirements and the customer requirements and product function requirements, and the autocorrelation relations of engineering characteristics are often fully considered.. DEMATEL is an effective method to analyze the interaction relationship between systems, using DEMATEL method to obtain the autocorrelation relations of product function requirements by analyzing the interaction relationship between the product function requirements, then to modify the importance degree of product function requirements obtained by traditional QFD method, so that to make the calculation results more objective and accurate.

Calculation based on the Initial Importance Degree of QFD Product Functional Requirements

Assuming that the customer demands obtained through interviewing customers and experts and surveying in the process of product design is $CR_i \ \left(i=1,2,\ldots,m\right)$, product function requirements $EC_j \ \left(j=1,2,\ldots,n\right)$. By $p$experts to evaluate the correlation relationship between the importance degree of customer requirements and customer requirements and product function requirements using semantic variable, and then using the triangular fuzzy number to process the semantics valuation results are given by experts.

$\tilde{w}_i^{\langle k\rangle}$ represents the number $k \left(k=1,2,\ldots,p\right)$ evaluation of experts for the importance degree of customer requirements CR_i . Using the arithmetic mean method to calculate the group decision value of importance degree $\tilde{w}_i$ of customer requirements.

$$\tilde{w}_i = \frac{1}{p} \otimes \left(\tilde{w}_i^{\langle 1\rangle} \oplus \tilde{w}_i^{\langle 2\rangle} \oplus \cdots \oplus \tilde{w}_i^{\langle p\rangle}\right) \tag{1}$$

$\tilde{r}_{ij}^{\langle k\rangle}$ represents the number $k \, \tilde{w}_i^{\langle k\rangle}$ evaluation of experts for the correlation relationship between customer requirements CR_i and product function requirements EC_j . Using the arithmetic mean method to calculate the group decision-making value of correlation relationship between customer requirementsand product function requirements, $\tilde{r}_{ij}$ makes up the correlation relationship matrix $\tilde{R}$ between the customer requirements and product function requirements.

$$\tilde{r}_{ij} = \frac{1}{p} \otimes \left(\tilde{r}_{ij}^{\langle 1\rangle} \oplus \tilde{r}_{ij}^{\langle 2\rangle} \oplus \cdots \oplus \tilde{r}_{ij}^{p}\right) \tag{2}$$

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1n} \\ \tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{m1} & \tilde{r}_{m2} & \cdots & \tilde{r}_{mn} \end{bmatrix}$$

Based on QFD calculation method, the importance degree $\tilde{w}_j^{'}$ of product function requirements EC_j is:

$$\tilde{w}_j^{'} = \sum_{i=1}^{m} \tilde{w}_i \cdot \tilde{r}_{ij} \tag{3}$$

Modify the Importance Degree of DEMATEL Product Function Requirements

Step 1: Establish the fuzzy initial direct relation matrix $\tilde{Z}^{\langle k\rangle}$.

P experts evaluate the interaction relationship between product function requirements using semantics variable. $\tilde{Z}^{\langle k\rangle}$ is the fuzzy initial direct relationship matrix obtained by the number k $\left(k=1,2,\ldots,p\right)$ experts through evaluation:

$$\tilde{Z}^{\langle k\rangle}=\begin{bmatrix} 0 & \tilde{z}_{12}^{\langle k\rangle} & \cdots & \tilde{z}_{1n}^{\langle k\rangle} \\ \tilde{z}_{21}^{\langle k\rangle} & 0 & \cdots & \tilde{z}_{2n}^{\langle k\rangle} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1}^{\langle k\rangle} & \tilde{z}_{n2}^{\langle k\rangle} & \cdots & 0 \end{bmatrix}$$

Among it, $\tilde{z}_{ij}^{\langle k\rangle}=\left(l_{ij}^{\langle k\rangle},m_{ij}^{\langle k\rangle},u_{ij}^{\langle k\rangle}\right)$ represents the influence degree of $ECi\left(i=1,2,\ldots,n\right)$ to$ECj\left(j=1,2,\ldots,n\right)$, and $\tilde{z}_{ii}^{\langle k\rangle}(i=1,2,\ldots,n)$ is (0, 0, 0) constantly on the main diagonal.

Step 2: Calculate the standard fuzzy initial direct relationship matrix $\tilde{X}^{\langle k\rangle}$.

To standard and obtain the standard fuzzy initial direct relationship matrix $\tilde{X}^{\langle k\rangle}$:

$$\tilde{X}^{\langle k\rangle}=\begin{bmatrix} \tilde{x}_{11}^{\langle k\rangle} & \tilde{x}_{12}^{\langle k\rangle} & \cdots & \tilde{x}_{1n}^{\langle k\rangle} \\ \tilde{x}_{21}^{\langle k\rangle} & \tilde{x}_{22}^{\langle k\rangle} & \cdots & \tilde{x}_{2n}^{\langle k\rangle} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1}^{\langle k\rangle} & \tilde{x}_{n2}^{\langle k\rangle} & \cdots & \tilde{x}_{nn}^{\langle k\rangle} \end{bmatrix}$$

Among $\tilde{x}_{ij}^{\langle k\rangle}=\dfrac{\tilde{z}_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}}=\left(\dfrac{l_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}},\dfrac{m_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}},\dfrac{u_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}}\right)$, $r^{\langle k\rangle}$ is the maximum value on the sum of each line's elements of matrix $\tilde{Z}^{\langle k\rangle}$,

that is $r^{\langle k\rangle}=\max\limits_{1\le i\le n}\left(\sum_{j=1}^{n}u_{ij}^{\langle k\rangle}\right)$.

Step 3: Calculate the arithmetic average of $\tilde{X}^{\langle 1\rangle},\tilde{X}^{\langle 2\rangle},\ldots,\tilde{X}^{\langle p\rangle}$ and get group decision-making matrix $\tilde{X}$.

Using arithmetic average method to average of the standard initial direct relationship fuzzy matrix $\tilde{X}^{\langle 1\rangle},\tilde{X}^{\langle 2\rangle},\ldots,\tilde{X}^{\langle p\rangle}$ obtained through evaluation from each expert and get the corresponding group decision-making matrix $\tilde{X}$:

$$\tilde{X}=\frac{\left(\tilde{X}^{\langle 1\rangle}\oplus\tilde{X}^{\langle 2\rangle}\oplus\cdots\oplus\tilde{X}^{\langle p\rangle}\right)}{p}$$

$$\tilde{X}=\begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nn} \end{bmatrix}$$

Among it,

$$\tilde{x}_{ij}=\sum_{k=1}^{p}\tilde{x}_{ij}^{\langle k\rangle}\Big/p\,.$$

Step 4: Calculate the overall fuzzy relationship matrix $\tilde{T}$.

In order to calculate the overall fuzzy relationship matrix $\tilde{T}$, we must ensure $\lim_{w\to\infty} \tilde{X}^{w} = 0$ firstly.

Assuming $\tilde{N}_1 = (l_1, m_1, u_1)$ and $\tilde{N}_2 = (l_2, m_2, u_2)$ are two triangular fuzzy Numbers, then $\tilde{N}_1 \otimes \tilde{N}_2$ can be approximated into $(l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$, that is, $\tilde{N}_1 \otimes \tilde{N}_2 \cong (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$.

Fuzzy overall relationship matrix $\tilde{T}$:

$$\tilde{T} = \lim_{w\to\infty}\left(\tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^w\right) = \tilde{X} \times (I - \tilde{X})^{-1}$$

$\tilde{D}_i$ is the sum of each line's elements of overall relationship matrix $\tilde{T}$ and represents the overall influential strength of ECi to other product function requirements; $\tilde{R}_i$ is the sum of each column's elements of overall relationship matrix $\tilde{T}$ and represents the overall influential strength of other product function requirements to ECi; $\tilde{D}_i + \tilde{R}_i$ is called the overall influential strength of ECi; $\tilde{D}_i - \tilde{R}_i$ is call the static influential strength of ECi.

Step 5: Calculate the modify importance degree wj of product function requirements.

To add the static influential strength $\tilde{D}_i - \tilde{R}_i$ of product function requirements and the initial importance degree $\tilde{w}_j^{'}$ of product function requirements, thus modify the important degree of product function requirements and get fuzzy modification important degree $\tilde{w}_j$ of product function requirements.

$$\tilde{w}_j = \tilde{w}_j^{'} + \tilde{D}_i - \tilde{R}_i$$

In order to get precise modification importance degree wj, we need to fuzzy process $\tilde{w}_j$, the paper processes cancel fuzzy for $\tilde{w}_j$ using CFCS cancel fuzzy method. Assuming $\tilde{N}_k = (l_k, m_k, u_k), k = 1, 2, \ldots, n$ as a group of triangular fuzzy number, $L = \min(l_k), R = \max(u_k), \Delta = R - L$ and Nk are its cancel fuzzy precise value.

$$N_k = L + \Delta \times \frac{(m_k - L)(\Delta + u_k - m_k)^2 (R - l_k) + (u_k - L)^2 (\Delta + m_k - l_k)^2}{(\Delta + m_k - l_k)(\Delta + u_k - m_k)^2 (R - l_k) + (u_k - L)(\Delta + m_k - l_k)^2 (\Delta + u_k - m_k)}$$

ANALYZE THE CONSUMER SATISFACTION DEGREE BASED ON QUANTIFY KANO MODEL

KANO model divides customer requirements into basic demand (M), expected demand(O), excited demand(A), deparate demand(I), contrary demand(R) and problem demand(Q). Each requirement type has different features:

1) Basic demand refers to when a certain engineering properties aremet, the customer satisfaction degree won't improve a lot, but when unmeet, customer satisfaction degree will cause strong dissatisfaction.

2) Expect demand refers to when a project properties are met, the customer satisfaction degree will rise, when unmet, the customer satisfaction degree will decline.

3) Excited demand refers to when a project properties is met, the customer satisfaction degree will surge, but unmeet, the customer satisfaction degree will not be too big effected and can be accepted.

4) Deparate demand refers to whether a certain engineering properties exist or not, the customer satisfaction degree will not be effected.

Contrary demand refers to when a certain engineering properties are met, customer satisfaction does not rise, but fall, on the contrary, when unmet, customer satisfaction degree will rise.

Analyze the Product Function Requirement based on Fuzzy Theory

In order to study the type of product function requirements in KANO model, our survey need to be helped by means of questionnaire. Traditional KANO model surveys the classification of the product function requirements with KANO questionnaire, but the evaluation standard of traditional KANO questionnaireis single, the respondents can only choose a best option from multiple evaluation options, which can not fully reflect the respondents' complex ideas to a certain demand. Aimed at the disadvantages, based on traditional KANO questionnaire to combine the fuzzy theory and design the fuzzy KANO questionnaire thatuses percentage formto instead of the form of only choosing a option in traditional KANO questionnaire. Table 1 is the comparison between traditional KANO questionnaire and fuzzy KANO questionnaire.

Table 1. The comparison between traditional KANO questionnaire andfuzzy KANO questionnaire.

Product function	Traditional kano questionnaire(∨)				
	Satisfaction	Must like this	Neutral	Can tolerate	Unsatisfication
Can realize					
Can not realize					
Product function	Fuzzy kano questionnaire(%)				
	Satisfaction	Must like this	Neutral	Can tolerate	Unsatisfication
Can realize					
Can not realize					

U and V respectively represent positive and negative problems collection in the KANO model. $P=\{P_1,P_2,\ldots,P_m\}$ and $N=\{N_1,N_2,\ldots,N_n\}$ respectively representthat can optional semantic evaluation variables collection under the situation that a certain function requirements can be implemented and cannot be implemented in KANO questionnaire. $m(P)_{ki}$ and $m(N)_{ki}$ respectively represent that the number*k* (*k* = 1, 2, and *p*) expert' evaluation vector to product function requirements *ECi*that can be implemented and cannot be implemented after quantization, and meet $\sum_{i=1}^{m} m(P)_{ki}=1$ and $\sum_{j=1}^{n} m(N)_{kj}=1$. S_{ij}^{k} represents the evaluation matrix of number *k*respondentors to this function, and $S_{ij}^{k}=m(P)_{ki}{}^{T}\otimes m(N)_{kj}$.

Comparing the evaluation matrix S_{ij}^{k} with the KANO model requirement classification evaluation table (Table 2) and calculating the sum T_h^k of evaluation value of each requirement type *h* (*h* = M, O, A, I, R, Q) in evaluation matrix S_{ij}^{k}, that is, $T_h^k=\sum S_{xy}^{k}$, T_h^k reflects the *h* class customer requirements degree that includes this function.

In order to further reduce the individual's subjective factors' influence on the evaluation results, the paper uses the α cut to modify T_h^k, if $T_h^k \ge \alpha$, then $\{T_h^k\}_\alpha=1$, otherwise, $\{T_h^k\}_\alpha=0$, then $\{T_h^k\}_\alpha$ is obtained. The modification value

Table 2. The KANO model requirement classification evaluation table.

Can realize	**Cannot realize**				
	Satisfaction	**Must like this**	**Neutral**	**Can tolerate**	**Unsatisfication**
Satisfaction	Q	A	A	A	O
Must like this	R	I	I	I	M
Neutral	R	I	I	I	M
Can tolerate	R	I	I	I	M
Unsatisfication	R	R	R	R	Q

Table 3. The evaluation information statistics table.

Type of requirement	**M**	**O**	**A**	**I**	**R**	**Q**
Expert 1						
Expert 2						
Expert 3						
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Expert p						
Cri frequency						

$\left\{T_h^k\right\}_\alpha$ of all respondents to evaluate are recorded in the Table 3 and to get the evaluation information statistics table.

According to the calculation results in Table 3 to record the product function requirement *ECi* frequency in turn in Table 4, and get KANO model requirement classification evaluation results. The type of customer requirements of highest frequency is the requirementtype of the product function, if there are two types with the same frequency, priority level of the classification of the demand is divided into M, O, A and I in turn.

Table 4. The KANO model requirement classification evaluation results.

Customer requirement	**M**	**O**	**A**	**I**	**R**	**Q**	**Summation**	**Classification**
EC1								
EC2								
EC3								
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
EC6								

KANO Model Quantification Analysis

To achieve fuzzy quantification of KANO model, the paper uses the equation $s_i = af\left(x_i\right) + b$ to fit the curve S-CR in figure, in which *si* represents the customer satisfaction degree that influenced by the product function requirements *ECi*. *xi* represents the satisfaction degree of the product function requirements *ECi* , *a* and *b* are the parameters for curve, *f* represents thetype of equation that fits with different curve S-CR.

Assuming*fh*(*h* = M, O, A, I, R, Q) as the frequency number of various requirement type of the product function requirements*CRi*, *CSi*is the satisfaction degree of the customer to product function requirements*CRi*, *DSi*is the unsatisfaction degree of the customer to product function requirements*CRi*.

$$CS_i = \frac{f_A + f_O}{f_A + f_O + f_M + f_I}$$

$$DS_i = -\frac{f_O + f_M}{f_A + f_O + f_M + f_I}$$

1.The fitting equation of excited type curve S-CR is $s_i = a_1 e^{x_i} + b_1$, assuming (1，*CSi*) and(0，*DSi*)as two points on the curve, then the parameters *a1*and *b1* as follows:

$$a_1 = \frac{CS_i - DS_i}{e-1}, \quad b_1 = -\frac{CS_i - eDS_i}{e-1}$$

2.The fitting equation of expected type curve S-CR is $s_i = a_2 x_i + b_2$, assuming (1，*CSi*) and(0，*DSi*)as two points on the curve, then the parameters *a2*and *b2*as follows:

$$a_2 = CS_i - DS_i, \quad b_2 = DS_i$$

3.The fitting equation of basic type curve S-CR is $s_i = a_3\left(-e^{-x_i}\right) + b_3$, assuming (1，*CSi*) and(0，*DSi*)as two points on the curve, then the parameters *a3*and *b3* as follows:

$$a_3 = \frac{e\left(CS_i - DS_i\right)}{e-1}, \quad b_3 = \frac{eCS_i - DS_i}{e-1}$$

Based on the above analysis and calculation to get the customer satisfaction degree equation as follows:

$$s_i = \begin{cases} \frac{CS_i - DS_i}{e-1} e^{x_i} - \frac{CS_i - eDS_i}{e-1} & (A) \\ \left(CS_i - DS_i\right) x_i + DS_i & (O) \\ -\frac{e\left(CS_i - DS_i\right)}{e-1} e^{-x_i} + \frac{eCS_i - DS_i}{e-1} & (M) \end{cases}$$

NONLINEAR OPTIMIZATION OF PRODUCT FUNCTION REQUIREMENTS

The type of product function requirements *ECi*can be also divided into the efficiency type and cost type, efficiency type represents that the greater of index value, the better it is, cost type represents that the lower of index value, the better it is. Assuming the product functional requirements *ECi*totally has *s* engineering property values, X_i^t represents the number t $\left(t = 1, 2, \ldots, s\right)$ engineering property value, the satisfaction degree *xi* of the product function requirements *ECi*can be represented as:

$$x_i = \frac{X_i^t - \min_s X_i^t}{\max_s X_i^t - \min_s X_i^t} \quad \text{(efficiency type)}$$

$$x_i = \frac{\max_s X_i^t - X_i^t}{\max_s X_i^t - \min_s X_i^t} \quad \text{(cost type)}$$

Making the maximize customer satisfaction degree as the goal to establish the nonlinear programming model:

$$\max \sum_{i=1}^{n} w_i s_i$$

$$s_i = \begin{cases} \dfrac{CS_i - DS_i}{e-1} e^{x_i} - \dfrac{CS_i - eDS_i}{e-1} & (A) \\ \left(CS_i - DS_i\right) x_i + DS_i & (O) \\ -\dfrac{e\left(CS_i - DS_i\right)}{e-1} e^{-x_i} + \dfrac{eCS_i - DS_i}{e-1} & (M) \end{cases}$$

$$s.t. \;\; x_i = \begin{cases} \dfrac{X_i^t - \min_s X_i^t}{\max_s X_i^t - \min_s X_i^t} \\ \dfrac{\max_s X_i^t - X_i^t}{\max_s X_i^t - \min_s X_i^t} \end{cases}$$

$$\sum_{t=1}^{s} Y_i^t = 1 \;,\; \sum_{i=1}^{n}\sum_{t=1}^{s} C_i^t Y_i^t \le B \;,\; Y_i^t \in \{0,1\}$$

Among them, the value of Y_i^t is 0 and 1, when $Y_i^t = 1$, which represents to select this project property value X_i^t, when $Y_i^t = 0$ represents don't to select this property value. C_i^t represents the cost of this engineering property value X_i^t, B represents the total cost limitation of the product.

CASE ANALYSIS

With the development of economy and the progress of science and technology, people has higher requirement for quality of life, which also contribute to the rise of smart home furnishing industry. A certain enterprise is the enterprise of r&d and manufacturing of the smart home furnishing that mainly produces household sweeping machine. In order to promote the development of smart home furnishing market and keep its strong competitive advantage in the smart home furnishing market, the enterprise hope to do the further exploration and optimization design for the product function requirements of emerging product, so that to better meet the demand of customers and improve customer satisfaction degree. This paper makes the household sweeping machine as example and using proposed method to deep research and analyze the product function requirements, so as to optimize design.

Through the interview and survey for customers and experts to obtain the customer requirements in the product planning, which includes: long life (*CR1*), efficient sweeping (*CR2*), complex environment (*CR3*), easy operation (*CR4*) and humanized design (*CR5*). The product function requirements of sweeping machine include: low noise (*FR1*), large applicable area (*FR2*), long life time (*FR3*), great capacity of dust (*FR4*), cleaning mode diversity (*FR5*), strong obstacle capability (*FR6*), thin airframe (*FR7*), radius of the fuselage (*FR8*) and strong suction (*FR9*).

20 experts composed of a group of experts, using semantic evaluation variable {very high (VH), high (H), middle (M), low (L) and very low (VL)} to evaluate the important degree of customer requirements, the evaluation results uses triangular fuzzy number to quantify, the conversion relationship between semantic evaluation variables and the triangular fuzzy number is shown in Table 5, the semantic evaluation results and fuzzy importance degree of the importance degree of customer requirements is shown in Table 6. Also to semantic evaluate the correlation relationship between the customer requirements and product function requirements by groups of experts, and get the fuzzy correction relationship matrix between the customer requirements and product function requirements after quantifying the evaluation results, which is shown in Table 7.

Table 5. The conversion relationship between semantic evaluation variables and the triangular fuzzy number.

Semantic evaluation variables	VL	L	M	H	VH
Relative triangular fuzzy number	(0, 0, 0.3)	(0, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.7, 1, 1)

Table 6. The semantic evaluation results and fuzzy importance degree of the importance degree of customer requirements.

	VL	L	M	H	VH	Fuzzy importance degree
CR1	2	2	5	9	2	(0.370, 0.570, 0.760)
CR2	0	0	1	10	9	(0.580, 0.825, 0.935)
CR3	3	4	11	2	0	(0.215, 0.405, 0.620)
CR4	3	6	8	3	0	(0.195, 0.395, 0.610)
CR5	5	9	4	1	1	(0.120, 0.320, 0.535)

Table 7. The fuzzy correction relationship matrix between the customer requirements and product function requirements.

	FR1	***FR2***	⋯	***FR8***	***FR9***
CR1	(0.015, 0.145, 0.400)	(0.325, 0.545, 0.730)	⋯	(0.195, 0.415, 0.615)	(0.275, 0.490, 0.680)
CR2	(0.030, 0.140, 0.400)	(0.345, 0.550, 0.740)	⋯	(0.155, 0.335, 0.560)	(0.590, 0.850, 0.930)
CR3	(0.015, 0.115, 0.380)	(0.400, 0.630, 0.790)	⋯	(0.340, 0.565, 0.755)	(0.195, 0.410, 0.620)
CR4	(0.015, 0.130, 0.390)	(0.060, 0.205, 0.450)	⋯	(0.070, 0.245, 0.480)	(0.175, 0.345, 0.565)
CR5	(0.575, 0.840, 0.920)	(0.155, 0.350, 0.570)	⋯	(0.165, 0.335, 0.555)	(0.095, 0.220, 0.470)

According to the formula (3, 4) to calculate and get the fuzzy initial importance degree of product function requirements {(0.0981, 0.5649, 1.6437), (0.4366, 1.2125, 2.3160), (0.4534, 1.2239, 2.3126), (0.3642, 1.0967, 2.2003), (0.5179, 1.4396, 2.6010), (0.4322, 1.2532, 2.3643), (0.2616, 0.9104, 2.0033), (0.2686, 0.9457, 2.0488), (0.5314, 1.3533, 2.3669)}

Using DEMATEL method to modify the initial importance degree of function requirements, the first thing you need the group of experts to semantic evaluation the interaction relationship between the function requirements. Like to calculate correlation matrix between customer requirements and function requirements are similar, using triangular fuzzy number to quantify the evaluation result to get the fuzzy initial direct relationship matrix between the function requirements. According to the formula (5-7) to standard the fuzzy initial direct relationship matrix, and to calculate the group decision-making matrix, so that to obtainthe standardization fuzzy direct relationship matrix $\tilde{X}$ between function requirements, as shown in Table 8. Through the formula (8) to calculate and get the fuzzy overall relationship matrix $\tilde{T}$, as shown in Table 9, and then calculate the static influence strength degree $\tilde{D}_j - \tilde{R}_j$ of function requirements *FRj*, and then through the formula (9) to calculate the modification importance degree $\tilde{w}_j$ of function requirements, finally using formula (10) to cancel fuzzy for $\tilde{w}_j$ and get the precise values ofimportance degree of product function requirements. The calculation results of the important degree of product is shown in Table 10.

Table 8. The fuzzy direct relationship matrix of product function requirements standardization.

	FR1	*FR2*	⋯	*FR8*	*FR9*
FR1	(0, 0, 0)	(0, 0.018, 0.063)	⋯	(0.007, 0.031, 0.078)	(0.069, 0.108, 0.135)
FR2	(0.005, 0.032, 0.074)	(0, 0, 0)	⋯	(0.040, 0.073, 0.109)	(0.013, 0.045, 0.084)
⋮	⋮	⋮	⋱	⋮	⋮
FR8	(0.036, 0.072, 0.107)	(0.034, 0.068, 0.104)	⋯	(0, 0, 0)	(0.083, 0.124, 0.147)
FR9	(0.083, 0.123, 0.148)	(0.076, 0.117, 0.143)	⋯	(0.051, 0.084, 0.120)	(0, 0, 0)

Table 9. The fuzzy overall relationship matrix of product function requirements.

	FR1	*FR2*	⋯	*FR8*	*FR9*
FR1	(0.005, 0.043,0.427)	(0.009, 0.082,0.581)	⋯	(0.017,0.091,0.570)	(0.081, 0.176,0.674)
FR2	(0.016, 0.098,0.579)	(0.022, 0.104,0.626)	⋯	(0.057,0.160,0.697)	(0.031, 0.149,0.726)
⋮	⋮	⋮	⋱	⋮	⋮
FR8	(0.099, 0.213,0.767)	(0.105, 0.251,0.900)	⋯	(0.074,0.201,0.838)	(0.034, 0.147,0.795)
FR9	(0.026, 0.119,0.618)	(0.045, 0.169,0.747)	⋯	(0.086,0.209,0.768)	(0.090, 0.215,0.811)

Table 10. The importance degree of product function requirements.

	FR1	*FR2*	⋯	*FR8*	*FR9*
$\tilde{w}_j^{'}$	(0.098,0.565,1.644)	(0.437,1.213,2.316)	⋯	(0.269,0.946,2.049)	(0.531,1.353,2.367)
$\tilde{D}_j - \tilde{R}_j$	(-0.106,-0.298,-0.679)	(-0.235,-0.456,-0.990)	⋯	(0.656,0.274,0.716)	(-0.197,-0.384,-0.942)
$\tilde{w}_j$	(-0.008,0.565,1.644)	(0.202,1.213,2.316)	⋯	(0.925,0.946,2.049)	(0.335,1.353,2.367)
w_j	0.362	0.792	⋯	1.469	0.959

Using the fuzzy KANO questionnaire to investigate the type of the function requirements, in the questionnaire, $P = N$ = {satisfaction, must like this, neutral, can tolerance, unsatisfication}, $m = N = 5$. There are totally 200 questionnaires, respondents are developers, customers buying the products, sales staff and random people and back and sort out 169 effective questionnaire to ensure the validity of the questionnaire. Among them, the number k respondent's the fuzzy KANO questionnaire result for low noise (*FR1*) this product function requirements is shown in Table 9, and according to the results in Table 11 to calculate $m(P)_{k1}$ = (0.5, 0.2, 0.3, 0, 0) and $m(N)_{k1}$ = (0, 0, 0.5, 0.4, 0.4).

Table 11. The questionnaire result of a certain respondent for low noise (*FR1*).

Low noise (*FR1*)	**Fuzzy KANO questionnaire (%)**				
	Satisfaction	**Must like this**	**Neutral**	**Can tolerant**	**Unsatisfaction**
Can realize	50	20	30	0	0
Cannot realize	0	0	50	40	10

Through the formula (11) to calculate the evaluation matrix of respondents for low noise (*FR1*), and to compare the matrix with KANO model requirement classification evaluation table (Table 2) , calculate $T_{\mathrm{M}}^{\langle k\rangle}$ = 0.05, $T_{\mathrm{O}}^{\langle k\rangle}$=0.05, $T_{\mathrm{A}}^{\langle k\rangle}$ = 0.45, $T_{\mathrm{I}}^{\langle k\rangle}$ = 0.45, $T_{\mathrm{R}}^{\langle k\rangle}$ = 0, $T_{\mathrm{Q}}^{\langle k\rangle}$ = 0. Using the *a* cut to revise $T_h^{\langle k\rangle}$, this paper takes *a* as 0.4, if $T_h^{\langle k\rangle} \ge 0.4$, then $\left\{T_h^{\langle k\rangle}\right\}_{0.4} = 1$, otherwise, $\left\{T_h^{\langle k\rangle}\right\}_{0.4} = 0$, the revised values $\left\{T_h^{\langle k\rangle}\right\}_{0.4}$ of all the respondents' evaluation are record in Table 12 in turn to get function requirements *FRi* evaluation information statistics table.

Table 12. The evaluation information statistics table of requirement type for low noise (*FR1*)

Requirement type	**M**	**O**	**A**	**I**	**R**	**Q**
Respondent 1	0	0	1	1	0	0
Respondent 2	0	0	1	0	0	0
Respondent 3	0	0	0	1	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Respondent*169*	0	0	1	1	0	0
Summation (*fri* frequency number*fh*)	32	20	128	51	0	2

Similar to the above analysis process to calculate the classification frequency number *fh* of all product function requirements *FRi*, and through the formula (12, 13) to respectively calculate the *CSi*value and *DSi*value of each function requirements, the above calculation results are recorded in turn in Table 11 to get the KANO model function requirements classification evaluation result. According to the classification evaluation results of the function requirements in Table 13, by the formula (14-17) to calculatethe curve S-FR fitting equation of each product function requirements, the calculation results is shown in Table 14.

Table 13. The classification evaluation results of the function requirements.

Function requirements	M	O	A	I	R	Q	Classification	*Csi*	*Dsi*
FR1	32	20	128	51	0	2	A	0.641	-0.307
FR2	110	80	31	13	0	12	M	0.474	-0.397
FR3	131	56	28	40	0	9	M	0.329	-0.376
FR4	82	108	10	29	2	14	O	0.515	-0.598
FR5	60	90	106	17	1	7	A	0.718	-0.392
FR6	70	121	51	20	1	11	O	0.656	-0.538
FR7	90	113	59	33	0	9	O	0.583	-0.495
FR8	87	98	50	23	5	22	O	0.574	-0.469
FR9	109	86	57	19	0	9	M	0.528	-0.387

Table 14. The curve S-FR fitting equation of each product function requirements.

Function requirements	Classification	*A*	*B*	*F*(*xi*)	$s_i = af(x_i) + b$
FR1	A	0.552	-0.859	e^{x_i}	*s1*=0.552 e^{x_1} -0.859
FR2	M	1.379	0.982	$-e^{-x_i}$	*s2*=-1.379 e^{-x_2} +0.982
FR3	M	1.117	0.740	$-e^{-x_i}$	*s3*=-1.117 e^{-x_3} +0.740
FR4	O	1.114	-0.598	*xi*	*s4*=1.114 x_4 -0.598
FR5	A	0.646	-1.038	e^{x_i}	*s5*=0.646 e^{x_5} -1.038
FR6	O	1.195	-0.538	*xi*	*s6*=1.195 x_6 -0.538
FR7	O	1.078	-0.495	*xi*	*s7*=1.078 x_7 -0.495
FR8	O	1.043	-0.469	*xi*	*s8*=1.043 x_8 -0.469
FR9	M	1.448	1.060	$-e^{-x_i}$	*s9*=-1.448 e^{-x_9} +1.060

All the function requirements parameters and the costs of sweeping machine is shown in Table 15, by the formula (18, 19) to calculate the degree of realization of each function requirements parameters *xi*, combined with the curve 12S-FR fitting equation of the function requirements in Table 12 to establish nonlinear programming model, so as to calculate the each function demand parameters of the best function requirements optimization design programming under the total cost limitation(RMB 1800) in turn as: 60 dB, 150 m^2, 100 min, 1 L, 6 kinds, 2.5 cm, 80 mm, 340 mm and 500 pa.

To better verify the feasibility and effectiveness of the method used in this paper, several different product function requirements optimization design schemes are compared, as shown in figure 1. A0 represents that the optimization design scheme obtained in this paper, A1 represents that the optimization design scheme obtained doesn't using

Table 15. Each function requirements parameters and the costs

Product function requirement	Parameter/cost (RMB)				
Low noise(FR1)	40 dB/190	50 dB/155	60 dB/120	70 dB/90	80 dB/65
Large applicable area(FR2)	90 m2/90	100 m2/120	120 m2/160	150 m2/190	—
Long life (CR3)	80 min/180	90 min/220	100 min/260	120 min/310	—
Large integrated capacity(FR4)	0.3 L/35	0.4 L/45	0.5 L/50	0.7 L/65	1L/80
Cleaning mode diversity (CR5)	4/170	5/220	6/280	7/355	8/420
Strong obstacle capability (FR6)	1 cm/50	1.5 cm/70	2 cm/85	2.5 cm/95	—
Thin airframe (FR7)	60 mm/290	70 mm/240	80 mm/210	90 mm/190	100 mm/165
Radius of the fuselage (FR8)	300 mm/130	320 mm/180	340 mm/210	360 mm/260	380 mm/320
Strong suction (FR9)	350 Pa/260	400 Pa/300	500 Pa/370	600 Pa/440	700 Pa/500

DEMATEL method under the condition of modified the importance degree of product function requirements, A2 represents that the optimization design scheme obtained under the condition of doesn't using quantify KANO model to analyze and calculate the satisfaction degree of each function requirement, A3 isthe optimization design scheme obtained by the traditional method, that is, the initial importance degree of doesn't modify product function requirements, also doesn't calculation and analysis forthe satisfaction degree of each function requirement using quantification KANO model.

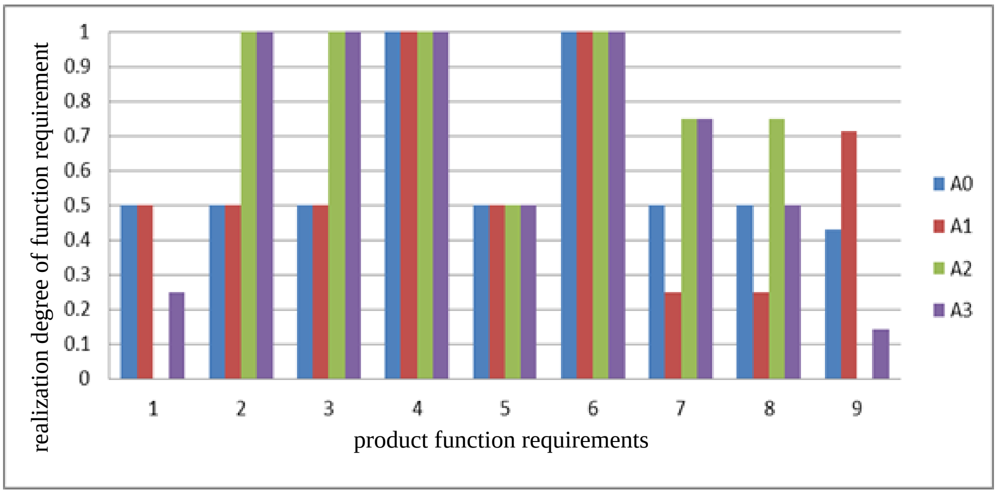

Figure 1. The optimization design schedule of product function requirements。

CONCLUSION

Customer satisfaction degree is the important basis to measure the success or failure of the product planning, so accuratelyand reasonable express the customer satisfaction degree becomes crucial. This paper makes the maximumrealize the customer satisfaction degree as the goal to establish the nonlinear programming model to optimize the product function requirements, the characteristics of method proposed are as follow:

(1) Fully consider the mutual influence relationship between product function requirements, using DEMATEL method to modify the initial importance degree of function requirements obtained by QFD to make the calculation ofimportant degree of the function requirements more accurate and reliable;

(2) Using KANO to analyze the satisfaction degree of product function requirements, and by S-FR equation to quantitatively analyze thefunction relationship between the realization degree of the function requirements and customer satisfaction degree in KANO model;

(3) combined S-FR equation with the importance degree of product function requirements to establish the objective function, so that makes the calculation of total customer satisfaction and the establishment of a nonlinear programming model that makes maximum realize customer satisfaction degree as goal more reasonable.

The optimization design analysis for product function requirements of a certain enterprise's sweeping machine shows the effectiveness and feasibility of the theory and methods proposed.

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