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# Research on Customer Requirement Prioritization of Engineering Products Based on Group Multi-Granularity Linguistic Information

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**Abstract:** Considering the ambiguity and uncertainty of information in the construction of an engineering product quality house, a method of determining customer requirements priority based on group multi-granularity linguistic information is proposed. This method starts with experts giving subjective decision information on customer requirements. Secondly, the priority of each demand can be obtained through consistency transformation and sequential optimization technology of the approximate ideal scheme. The effectiveness and practicability of the method is proven with an application example.

**Keywords:** Quality function deployment; House of quality; Comprehensive priority; Multi-granularity linguistic information

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## 1. Introduction

Quality function deployment (QFD) is a system engineering method that converts customer requirements into engineering characteristics in the stages of product development, design, and manufacturing in new product design and is reflected in the final product characteristics [1]. As a new customer-driven product design method, it has been widely used in many industries. The house of quality is the core tool of QFD, and the successful implementation of QFD largely depends on the accuracy of the construction of the house of quality [2]. The construction of customer needs priority is a very key step in the construction process of the house of quality, which has a great impact on the setting of the target value of engineering characteristics and the effective allocation of resources in the house of quality.

Current research on customer requirements mainly revolves around three aspects. The first aspect is obtaining the needs of customers. Customers' needs can be understood through surveys, observations, interviews, and other market research methods. Second, sorting and classifying the demand information collected first-hand. The tree diagram was introduced into the demand analysis and obtained a clear demand structure diagram. The research on the first two aspects has been very mature and recognized by the academic

circle, and the third aspect of research – the analysis of demand priority – has become a hot topic in QFD research. 1-3-5 or 1-5-9 scales are used to indicate the importance of customer requirements [3]. Accurate judgment becomes difficult with incomplete information, resulting in major errors in the conclusion. Analytic network process (AHP) or analytic hierarchy process (ANP) are used to determine the priority of customer requirements. The method requires the evaluator to make pair-based comparisons of demand to get an accurate number, which is difficult for the decision-makers [4]. Considering the assessment of environmental uncertainty, fuzzy set theory has been adopted to analyze the priority of customer requirements. However, the determination of the membership function of fuzzy theory is also a complex problem. Currently, scholars usually determine the function according to personal experience, which can be highly subjective.

The goal of most research studies is to quantify all the required items in decision-making. However, the information that an evaluator receives is often complex and uncertain, and the decision made will be affected by many factors such as the knowledge structure, experience, and background of the evaluator, which will make it very difficult to quantify many indicators [5]. Oftentimes, the items are evaluated qualitatively. For example, when weighing the need for strong ash cleaning ability, linguistic forms such as "important," "neutral," and "not important," are used. Due to the different knowledge levels and work experiences of the evaluators, their familiarity with the evaluation items is also different. Meanwhile, different linguistic scales are used for evaluating the level of priority of customer requirements [6]. Therefore, this paper proposes a method for determining the level of priority of customer requirements based on multi-granularity linguistic information of the group. Firstly, customer representatives are invited to select the appropriate linguistic scale, and the linguistic attribute values of importance and competitiveness of each customer requirement are given. A uniform matrix of the same granularity is constructed through the transformation function, and the level of priority is determined according to the deviations of importance and the positive and negative ideal points.

## 2. The method of customer requirements prioritization

The priority determination of customer requirements in the house of quality is a group evaluation process, which requires the selection of multiple heterogeneous personnel to ensure the rationality of the result. The variety of information in the engineering product design usually presents great uncertainty. Therefore, it is challenging to make accurate judgments on the priority of various customer needs, and the evaluation is often directly presented in the form of linguistic variables. Different members have different familiarity with customer needs, which results in differences in the linguistic granularity used in the evaluation process. The determination of the level of priority of customer requirements in the house of quality should not be based solely on the subjective evaluation of demand priority, but also on the market conditions. Evaluators should therefore use a multi-granularity linguistic scale in the competitive evaluation of customer requirements. Based on the above, this paper adopts an integrated method to determine the basic priority and competitive priority of each customer requirement. The method involves converting linguistic variables of different granularity into linguistic variables of the same granularity and then introducing the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) into the determination of basic priority and competitive priority.

Step 1: Through a comprehensive survey, the QFD team collects enterprise historical data and market information and then determines the customer needs. Customer representatives are invited to form an evaluation team, and the project leader explains the project requirements to the evaluation members. Evaluation members use linguistic variables to determine their weight vectors by a split vote method.

Step 2: The evaluators choose the appropriate linguistic granularity according to their discretion and

perform evaluation according to the linguistic variables. A multi-granularity evaluation matrix of the importance of customer needs is then constructed.

According to Equations (1) and (2), linguistic scales of different granularity are transformed into linguistic scales of the same granularity. During the transformation, the scale with the most occurrence in the evaluation matrix can be set as the basic scale, and a consistent matrix of the importance of customer needs can be established accordingly.

$$f: BS_{\alpha}^{\phi} \rightarrow BS_{\beta}^{\varphi} \quad (1)$$

$$\beta = f(\alpha) = \alpha^{\frac{\varphi-1}{\phi-1}} \quad (2)$$

Step 3: The evaluation vectors of the importance of each customer requirement are listed according to the matrix of the same granularity, and the positive ideal points and negative ideal points of each demand importance vector are determined by using Equations (3) and (4).

$$U^{+} = (u_1^{+}, u_2^{+}, \ldots, u_M^{+}) \quad (3)$$

$$V^{-} = (v_1^{-}, v_2^{-}, \ldots, v_M^{-}) \quad (4)$$

Step 4: According to Equations (5) and (6), the deviation between the importance vector of each customer requirement and the positive and negative ideal points is calculated.

$$BD_j^{+} = \rho_1 BD(\lambda_{11}, u_j^{+}) \oplus \rho_2 BD(\lambda_{21}, u_j^{+}) \oplus \ldots \oplus \rho_6 BD(\lambda_{61}, u_j^{+}) \quad (5)$$

$$BD_1^{-} = \rho_1 BD(\lambda_{11}, v_j^{-}) \oplus \rho_2 BD(\lambda_{21}, v_j^{-}) \oplus \ldots \oplus \rho_6 BD(\lambda_{61}, v_j^{-}) \quad (6)$$

Step 5: The relative proximity between the importance of each customer requirement and the positive and negative ideal points is calculated. The formula used to calculate the relative proximity is denoted as follows:

$$x_j^{*} = \frac{BD_j^{-}}{BD_j^{+} + BD_j^{-}} \quad (7)$$

Step 6: The greater the relative proximity of the importance of customer needs, the higher the basic priority of that customer needs. Then, the basic priority of customer requirements is obtained according to Equation (8).

$$bp_j = \frac{x_j^{*}}{\sum_{j=1}^{M} x_j^{*}} \quad (8)$$

## 3. Application examples

Company U is a well-known engineering equipment enterprise. Its main product is an LCDM long bag low-pressure pulse dust collector. The product has the advantages of a small carbon footprint, strong cleaning capacity, and high dust removal efficiency, and it has been widely used in cement, steel, and other industries. The main purpose of this product when it was introduced into the market was to achieve efficient production. However, the personalized needs of customers were neglected, which affected the expansion of its market share to a certain extent. To retain the advantage and make breakthroughs amidst the fierce competition, enterprises adopted the method proposed in this paper to determine the importance of customer requirements, and then redesign the product.

Step 1: In the early stage of the new product design, the QFD team determined the customer needs in the house of quality by organizing multiple surveys, field observations, inquiry methods, and group discussions were carried out. High dust removal efficiency, low emission concentration, easy operation and maintenance, high stability and reliability, small footprint, strong cleaning capacity, and long service life of filter bag and pulse valve were among the items for priority evaluation. The project leader invited 6 customer representatives from the target market to form an assessment team to participate in the determination of demand priority. The person in charge explained the enterprise's requirements for the project to the assessment team and clarified the tasks that the assessment team needed to complete. The evaluation members voted using linguistic information. The method proposed in this paper was then used to gather the decisions of the team members $\rho = \{0.153, 0.211, 0.178, 0.148, 0.124, 0.186\}$.

Step 2: Because of the different work experiences, cultural backgrounds and values, and the different understanding of various needs, different linguistic scales should be selected in determining the level of priority of various customer needs. A matrix based on the information given by the 6 evaluation members about the importance of the requirements was created.

$$B = \begin{array}{c} \\ ES1 \\ ES2 \\ ES3 \\ ES4 \\ ES5 \\ ES6 \end{array} \begin{array}{c} \begin{array}{ccccccc} CR_1 & CR_2 & CR_3 & CR_4 & CR_5 & CR_6 & CR_7 \end{array} \\ \begin{bmatrix} BS^4_{1/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_3 & BS^4_0 \\ BS^3_{2/3} & BS^3_0 & BS^3_{-2/3} & BS^3_{2/3} & BS^3_2 & BS^3_0 & BS^3_{2/3} \\ BS^5_4 & BS^5_0 & BS^5_1 & BS^5_4 & BS^5_1 & BS^5_2 & BS^5_2 \\ BS^4_{4/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_3 & BS^4_{1/3} \\ BS^4_{4/3} & BS^4_{4/3} & BS^4_0 & BS^4_{4/3} & BS^4_0 & BS^4_{1/3} & BS^4_{4/3} \\ BS^3_{2/3} & BS^3_{2/3} & BS^3_{2/3} & BS^3_{-2/3} & BS^3_{2/3} & BS^3_2 & BS^3_{-2/3} \end{bmatrix} \end{array}$$

The consistent matrix of the importance of customer needs was established by using Equation (1) and (2).

$$B^s = \begin{array}{c} \\ ES1 \\ ES2 \\ ES3 \\ ES4 \\ ES5 \\ ES6 \end{array} \begin{array}{c} \begin{array}{ccccccc} CR_1 & CR_2 & CR_3 & CR_4 & CR_5 & CR_6 & CR_7 \end{array} \\ \begin{bmatrix} BS^4_{1/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_3 & BS^4_0 \\ BS^4_1 & BS^4_0 & BS^4_{-1} & BS^4_1 & BS^4_3 & BS^4_0 & BS^4_1 \\ BS^4_3 & BS^4_0 & BS^4_{3/4} & BS^4_3 & BS^4_{3/4} & BS^4_{3/2} & BS^4_{3/2} \\ BS^4_{4/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_{4/3} & BS^4_{1/3} & BS^4_3 & BS^4_{1/3} \\ BS^4_{4/3} & BS^4_{4/3} & BS^4_0 & BS^4_{4/3} & BS^4_0 & BS^4_{1/3} & BS^4_{4/3} \\ BS^4_1 & BS^4_1 & BS^4_1 & BS^4_{-1} & BS^4_1 & BS^4_3 & BS^4_{-1} \end{bmatrix} \end{array}$$

Step 3: The evaluation vector of the importance of each customer requirement was listed according to the importance uniformity matrix, as shown in **Table 1**.

**Table 1.** The evaluation vector of the importance of each customer requirement

| | Evaluation vector |
|---|---|
| $\lambda_1$ | $(BS^4_{1/3}, BS^4_1, BS^4_3, BS^4_{4/3}, BS^4_{4/3}, BS^4_1)$ |
| $\lambda_2$ | $(BS^4_{4/3}, BS^4_0, BS^4_0, BS^4_{4/3}, BS^4_{4/3}, BS^4_1)$ |
| $\lambda_3$ | $(BS^4_{1/3}, BS^4_{-1}, BS^4_{3/4}, BS^4_{1/3}, BS^4_0, BS^4_1)$ |
| $\lambda_4$ | $(BS^4_{4/3}, BS^4_1, BS^4_3, BS^4_{4/3}, BS^4_{4/3}, BS^4_{-1})$ |
| $\lambda_5$ | $(BS^4_{1/3}, BS^4_3, BS^4_{3/4}, BS^4_{1/3}, BS^4_0, BS^4_1)$ |
| $\lambda_6$ | $(BS^4_3, BS^4_0, BS^4_{3/2}, BS^4_3, BS^4_{1/3}, BS^4_3)$ |
| $\lambda_7$ | $(BS^4_0, BS^4_1, BS^4_{3/2}, BS^4_{1/3}, BS^4_{4/3}, BS^4_{-1})$ |

According to Equations (3) and (4), the positive ideal points and negative ideal points of each customer requirements importance evaluation vector were listed as $U^+ = (BS^4_3, BS^4_3, BS^4_3, BS^4_3, BS^4_{4/3}, BS^4_3)$, $V^- = (BS^4_0, BS^4_{-1}, BS^4_0, BS^4_{1/3}, BS^4_0, BS^4_{-1})$.

Step 4: The deviation between the evaluation vector of the importance of customer requirement and the positive ideal point was calculated using Equation (5) to be as follows:

$BD^+_1 = 0.1813$, $BD^+_2 = 0.2563$, $BD^+_3 = 0.3100$, $BD^+_4 = 0.2100$, $BD^+_5 = 0.2050$, $BD^+_6 = 0.1400$, $BD^+_7 = 0.2875$.

The deviation between the evaluation vector of the importance of customer requirements and the negative ideal point was calculated using Equation (6) to be as follows:

$BD^-_1 = 0.2125$, $BD^-_2 = 0.1375$, $BD^-_3 = 0.0706$, $BD^-_4 = 0.1838$, $BD^-_5 = 0.1756$, $BD^-_6 = 0.2663$, $BD^-_7 = 0.1063$.

Step 5: According to Equation (7), the relative proximity between the evaluation vector of the importance of customer needs and the positive and negative ideal points was determined as follows:

$X^*_1 = 0.540$, $X^*_2 = 0.349$, $X^*_3 = 0.185$, $X^*_4 = 0.467$, $X^*_5 = 0.461$, $X^*_6 = 0.655$, $X^*_7 = 0.270$.

Step 6: According to Equation (8), the priority of each customer requirement was obtained as follows:

$bp_1 = 0.185$, $bp_2 = 0.119$, $bp_3 = 0.063$, $bp_4 = 0.160$, $bp_5 = 0.157$, $bp_6 = 0.224$, $bp_7 = 0.092$.

Therefore, it was concluded that the priority ranking of each customer requirement was $CR_6 > CR_1 > CR_4 > CR_5 > CR_2 > CR_7 > CR_3$.

The customer requirements prioritization method proposed in this paper fully considers the customers' needs more objectively and comprehensively. The results obtained were fed back to the enterprise, and the results were approved after being shared with relevant departments such as the production and sales departments. According to the feedback of enterprises, the application of this method has brought many benefits.

(1) Optimization of the resource allocation

The level of priority of each customer requirement provides an idea for product development, and allocating resources to important projects ensures maximum resource utilization.

(2) Improved customer satisfaction

Product design method based on QFD is centered on customer needs, ensuring that the order of customer needs is considered in product planning, design, and manufacturing. In this case, the perceived value of the product was greatly improved.

## 4. Conclusion

QFD has become the mainstream model of product innovation in the 21st century, and the determination of customer requirements priority has become an important topic in QFD research. A method of determining

customer requirements priority based on group multi-granularity linguistic information is proposed in this paper. In this method, evaluators select appropriate linguistic scales, evaluate each customer requirement, and construct a consistency evaluation matrix. TOPSIS is then introduced to obtain the level of priority of the customer requirements. This method has been applied in Company U for its main product, the LCDM long bag low-pressure pulse dust collector, and was proven effective and feasible in determining demand priority.

## Disclosure statement

The author declares no conflict of interest.

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