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Customer Requirement Importance Determination Method Based on Uncertain Language Information Entropy

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Abstract: To reflect the uncertainty of the objective environment in an effective way, a customer demand selection method based on information entropy of uncertain language is proposed. First, the customer representative uses uncertain language variables to represent the competitiveness of the company's products and those of its competitors. Secondly, the method of information entropy was used to determine the competitive priority of each customer demand item. Finally, taking the improvement of the PE crusher as an example, the practicability and reliability of the proposed method are illustrated.

Keywords: Quality function deployment; Customer demand; Information entropy; Uncertain language

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1. Introduction

The increasing competition and global marketing have redefined the production and design of enterprises' products, and the voice of customers has become a decisive factor in the success or failure of product planning and design [1]. Paying attention to customer needs and improving customer satisfaction has become a key link for enterprises to occupy an advantage in the competition. To achieve a more long-term competitive advantage, the product must be continuously innovated and improved according to the voice of the customer. In the process of product design and planning, the design of a product planning scheme and the selection of the best scheme are very critical steps.

Quality function deployment (QFD) is a customer demand-driven product design and development method, which is a system tool to convert customer voice into product engineering characteristics, component characteristics, planning characteristics, and product characteristics. Among them, the competitive analysis

of customer demand is an important output of QFD, which directly affects the subsequent analysis in other stages and the design of product planning schemes. The concept of selling point is introduced to judge the competitiveness of each customer demand [2]. Generally, when customers think that all products of similar enterprises perform poorly in a certain demand, the selling point of the product is stronger. When customers think that all companies' products perform very well in a certain need, the selling point of the product is weak. In the processing method, precise values are selected to describe, such as 1-1.2-1.5 to express the "weak", "medium", and "strong" selling points respectively [3]. The method of information entropy was used to analyze the competitiveness of products in customer demand items, which objectively reflects the product performance of the company and its competitors [4]. However, the traditional information entropy method requires the evaluation members to use clear values for analysis, which puts forward higher requirements, and the feasibility of the method is limited.

In the early stage of product design, the competitive information and data that can be obtained are very limited, and most of the information is uncertain and fuzzy [5]. To effectively deal with such ambiguity, evaluation members often prefer to directly provide some language information. For example, in application examples, Evaluation members use "weak, average, and strong" to judge the competition of the "strong adaptability" of the required project. In addition, due to the complexity of products, the uncontrollability of market trends, and the work experience and knowledge level of evaluation members, not all evaluation members can provide certain language phrases to represent the competitiveness of a certain demand. To make full use of evaluation information and human subjective initiative, this study uses an integrated approach of uncertain linguistic variables and information entropy to determine the competitiveness of customer demand.

2. The customer requirement importance determination method

Step 1: Enterprise resources for product improvement are limited, so it is necessary to treat each need separately and find more competitive projects. Conduct a panel discussion with decision-makers to identify key competitors that produce alternative or similar products and record them together with their products. By consulting the historical sales records in detail, the key customers of the enterprise are identified, and the customer representatives are invited to participate in the competitive evaluation of the demand projects. Then, the compromise voting method proposed is used to obtain the weight vector of the customer representatives.

Step 2: The invited customer representative uses uncertain linguistic variables to evaluate the competitiveness of the company's products and those of the competing company's products in each customer demand item, and based on this a competitive evaluation matrix of customer demand can be constructed. Then, according to the weight of the customer representative, the competitive evaluation matrix given by the customer representative is aggregated into the competitive group evaluation matrix.

Step 3: Different customer demand projects have different dimensions and dimensional units, to determine the competitiveness of each demand, the group evaluation matrix must be normalized, and the standardized evaluation matrix is obtained as $NGR = (n\tilde{r}_{hj})m \times n$.

For the benefit demand, the standardized calculation formula is

$$ng\tilde{r}_{hj}^{\mu} = \frac{\sigma_k + x - 1}{\sum_{k=1}^{t}(\vartheta_k + x - 1)} \quad (1)$$

$$ng\tilde{r}_{hj}^{v} = \frac{\vartheta_k + x - 1}{\sum_{k=1}^{t}(\sigma_k + x - 1)} \quad (2)$$

For cost-oriented requirements, the standardized calculation formula is

$$ng\tilde{r}_{hj}^{\mu} = \frac{1/(\vartheta_k + x - 1)}{\sum_{k=1}^{t} 1/(\sigma_k + x - 1)} \quad (3)$$

$$ng\tilde{r}_{hj}^{v} = \frac{1/(\sigma_k + x - 1)}{\sum_{k=1}^{t} 1/(\vartheta_k + x - 1)} \quad (4)$$

Step 4: According to the information entropy theory, when all competing products have the same or similar evaluation values on a certain customer demand, the competitiveness of the demand project is low; when all competing products have very large differences in evaluation values on a certain customer demand, the competitiveness of the demand project is relatively high. Therefore, this paper uses the method of information entropy to determine the competition of each customer demand. According to Shannon's information entropy theory, the entropy of the product about the demand item can be obtained by **Equation 5**. The information deviation degree of the requirement item can be obtained by **Equation 6**. Finally, the standardized competition coefficient of customer demand items can be obtained by **Equation 7**.

$$E_j = \tau\left(-1/ln\, m \sum_{h=1}^{m} np\tilde{r}_{hj}^{\mu}\, ln\, n\, p\tilde{r}_{hj}^{\mu}\right) + (1-\tau)\left(-1/ln\, m \sum_{h=1}^{m} np\tilde{r}_{hj}^{v}\, ln\, n\, p\tilde{r}_{hj}^{v}\right) \quad (5)$$

$$\varepsilon_j = 1 - E_j \quad (6)$$

$$gc_j = \frac{\varepsilon_j}{\sum_{j=1}^{n} \varepsilon_j} \quad (7)$$

3. Application examples

A machinery manufacturing enterprise in Sichuan province applied the QFD method to improve the core products, trying to continue to expand market share, PE series crusher is the advantage of the enterprise. As the main equipment for processing sand and gravel, mine production, and construction materials, series products can be used in mining, sand and gravel fields, cement plants, and other industries.

Step 1: The enterprise selects personnel from relevant departments of product improvement to form a QFD team to conduct the selection and evaluation of product planning schemes. The team organized market

research to obtain customer demand information, using the tree diagram to organize and analyze the scattered information, and obtained the demand project set of PE series crusher, respectively: higher crushing output, stronger adaptability, better product granularity, higher equipment flexibility, lower operating costs, and lower noise. Select 5 customer representatives from the key customers to evaluate the competitiveness of customer demand. Further, the weight vector of customer representatives is determined by the compromise voting method as $\omega = (0.241, 0.188, 0.192, 0.215, 0.164)$.

Step 2: To better reflect the ambiguity of information in competitive evaluation, customer representatives are invited to use uncertain language phrases to make judgments, as shown in **Table 1** to **Table 5**.

Table 1. The competitive evaluation matrix given by the customer representative DM_1

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_2	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_3	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$
Com_4	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$

Table 2. The competitive evaluation matrix given by the customer representative DM_2

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_2	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_3	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$
Com_4	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$

Table 3. The competitive evaluation matrix given by the customer representative DM_3

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$
Com_2	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$
Com_3	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$
Com_4	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$

Table 4. The competitive evaluation matrix given by the customer representative DM_4

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_2	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_3	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$
Com_4	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$

Table 5. Competitive evaluation matrix given by the customer representative DM_5

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_2	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{4/3}]$	$[S_0, S_{1/3}]$
Com_3	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$
Com_4	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{1/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_0, S_{1/3}]$	$[S_0, S_{4/3}]$

The weight vector of decision makers is combined with the competitive evaluation matrix of each customer demand, and the competitive group evaluation matrix of customer demand is constructed (**Table 6**).

Table 6. Competitive group evaluation matrix given by the customer representatives

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_{0.055}, S_{0.497}]$	$[S_{0.055}, S_{0.904}]$	$[S_{0.207}, S_{4/3}]$	$[S_{1/3}, S_{4/3}]$	$[S_{0.189}, S_{1.141}]$	$[S_{0.064}, S_{0.525}]$
Com_2	$[S_{0.190}, S_{0.904}]$	$[S_{0.119}, S_{1.118}]$	$[S_{1/3}, S_{4/3}]$	$[S_{0.270}, S_{1.145}]$	$[S_0, S_{4/3}]$	$[S_{0.064}, S_{0.525}]$
Com_3	$[S_{0.055}, S_{0.497}]$	$[S_{0.261}, S_{1.118}]$	$[S_{0.126}, S_{1.141}]$	$[S_{0.190}, S_{0.904}]$	$[S_0, S_{1/3}]$	$[S_{0.143}, S_{4/3}]$
Com_4	$[S_{0.278}, S_{1.169}]$	$[S_0, S_{0.252}]$	$[S_0, S_{1/3}]$	$[S_{0.055}, S_{4/3}]$	$[S_{0.278}, S_{1.169}]$	$[S_{0.143}, S_{4/3}]$

Step 3: It is easy to see that the larger the evaluation value of each customer demand, the better, belongs to the benefit attribute, and the group standardization matrix of customer demand competition is obtained according to **Equations 1** and **2** (**Table 7**).

Table 7. Competitive group standardization evaluation matrix given by the customer representatives

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Com_1	$[S_{0.202}, S_{0.278}]$	$[S_{0.195}, S_{0.314}]$	$[S_{0.199}, S_{0.342}]$	$[S_{0.199}, S_{0.337}]$	$[S_{0.200}, S_{0.332}]$	$[S_{0.195}, S_{0.284}]$
Com_2	$[S_{0.211}, S_{0.310}]$	$[S_{0.199}, S_{0.331}]$	$[S_{0.307}, S_{0.331}]$	$[S_{0.196}, S_{0.323}]$	$[S_{0.188}, S_{0.348}]$	$[S_{0.195}, S_{0.284}]$
Com_3	$[S_{0.202}, S_{0.278}]$	$[S_{0.208}, S_{0.331}]$	$[S_{0.194}, S_{0.327}]$	$[S_{0.191}, S_{0.304}]$	$[S_{0.188}, S_{0.267}]$	$[S_{0.200}, S_{0.349}]$
Com_4	$[S_{0.218}, S_{0.331}]$	$[S_{0.192}, S_{0.283}]$	$[S_{0.186}, S_{0.263}]$	$[S_{0.183}, S_{0.337}]$	$[S_{0.205}, S_{0.334}]$	$[S_{0.200}, S_{0.349}]$

Step 4: **Equations 5**, **6**, and **7** are used to obtain the entropy, deviation degree, and standardized competitive coefficient of each customer demand, as shown in **Table 8**.

Table 8. The information entropy calculation results of each customer demand

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
E_j	0.9824	0.9675	0.9515	0.9408	0.9420	0.9526
τ_j	0.0176	0.0325	0.0485	0.0592	0.0580	0.0474
gc_j	0.0669	0.1235	0.1842	0.2249	0.2204	0.1801

4. Conclusion

The method based on uncertain linguistic variables and information entropy proposed in this study can fully reflect the fuzziness in the competitive evaluation, and obtain the customer demand that the product performance of the enterprise is significantly different from that of the competitor. According to the competition of various demand items, the enterprise can design the product improvement planning plan in a targeted manner.

Disclosure statement

The authors declare no conflict of interest.

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