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The Determination Method of Product Engineering Features Based on Linguistic Variables

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Abstract: To overcome the problem of imprecise and unclear information in the development of quality functions, a method for determining the priority of engineering features based on mixed linguistic variables is proposed. First, the evaluation member uses the determined linguistic variable to give the correlation strength evaluation matrix of customer requirements and engineering features. Secondly, the relative importance of the evaluation member and customer requirements are aggregated. Finally, the priority of engineering features is obtained by calculating the deviation. The feasibility and practicability of this method are proven by taking the design of a new product of a long bag low-pressure pulse dust collector as an example.

Keywords: Quality function deployment; Engineering features; Linguistic variable; Priority ratings

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1. Introduction

The issue of using limited resources to design and produce products that reflect customer needs in a shorter period has become the bottleneck of the long-term development of enterprises. In this case, a new product development and design method, Quality function deployment (QFD), is widely used in many industries. QFD is a systematic method to transform customer requirements into engineering features of product development and design [1]. QFD helps research and development technicians determine the main engineering features that should be prioritized for resource investment and how to set the target value of engineering features.

The house of quality is the core tool of QFD, which can systematically demonstrate the relationship between engineering features and customer needs in a three-dimensional manner [2]. Prioritizing engineering features is a key step in building a house of quality. Research and development departments need to have a deep understanding of the engineering features of new products, but due to resource constraints such as time, budget, and technology, it is impossible to take all engineering features into account. Therefore, the determination of engineering feature priority has very important theoretical and practical significance.

The process of determining the priority of engineering features in product planning involves a lot of human judgment, and there are more subjective and fuzzy factors. In fact, customers have many demands on products, and some customer requirements may be related to multiple engineering features. Conversely, the design of a certain engineering feature will also affect multiple customer requirements. At present, most methods to convert customer requirements into engineering features are qualitative. The information obtained in the process of product design is usually limited, especially when designing a new product, the error is generally relatively large, resulting in the inevitable fuzziness in the evaluation process. Such factors increase the fuzziness in determining the priority of engineering features, and selecting an appropriate decision-making method becomes the problem to be solved in this paper.

A simple digital scale can be used to represent the relationship between engineering features and customer needs[3], but it is too subjective and arbitrary to reflect the fuzziness of the information environment. To accurately evaluate the uncertainty in the priority degree of engineering features, fuzzy theory was introduced to determine the priority degree of engineering features [4]. While the fuzzy theory has some advantages over the digital scaling method, the membership function of evaluation members must be determined when using fuzzy theory, and the type of fuzzy number (triangle or bell shape) is selected according to experience, so it may be less reliable [5].

In the actual planning process, it is not easy for the evaluation members to give accurate judgments. To better reflect the fuzziness of the evaluation object, linguistic variables become the preferred form of information. The method proposed considers the different assessment objects. If accurate assessment information can be obtained easily, the determined linguistic variables will be more applicable, which facilitates the subsequent decision-making process. If accurate assessment information is difficult to obtain, uncertain linguistic variables will be used to avoid the loss of assessment information.

2. The engineering features prioritization method

The determination of the priority of engineering features is the key step in the construction of the house of quality in enterprise product planning, and the reasonable determination of the priority of engineering features has a direct impact on the subsequent construction of the house of quality. The members involved in the evaluation of engineering features come from different fields and have different understandings of different evaluation objects, so they will choose their preferred linguistic variables in the evaluation process.

Step 1: The company invites members of relevant departments to form a QFD team to obtain customer requirements based on research information and determine the corresponding engineering features. The relative importance of members is determined by the compromise voting method.

Step 2: To determine the priority of engineering features, it is necessary to analyze the correlation between customer needs and engineering features. In this process, it is difficult to give accurate evaluation information due to the differences in knowledge structure, work experience, and values among the evaluation members. Therefore, linguistic variables are selected for evaluation and the correlation strength evaluation matrix is constructed accordingly.

Step 3: By aggregating the relative importance of assessment members and corresponding linguistic variables, Equation (1) is used to obtain comprehensive linguistic assessment information, and then a group assessment matrix of association strength is constructed.

$$mre_{ij} = \rho_1 fe^1{}_{ij} \oplus \rho_2 fe^2{}_{ij} \oplus \dots \oplus \rho_L fe^L{}_{ij} \quad (1)$$

Step 4: By aggregating the final importance of customer needs with comprehensive linguistic evaluation information, the linguistic variables of the priority of various engineering features are obtained by Equation (2), and the priority order of engineering features can be determined accordingly.

$$FS_{EC_j} = gir_1 mre_{1j} \oplus gir_2 mre_{2j} \oplus \ldots \oplus gir_M mre_{Mj} \quad (2)$$

Step 5: The priority of each engineering feature can be obtained by using Equation (3).

$$gfp_j = \frac{d(FS_{EC_j}, FS_{min}}{\sum_{j=1}^{N\Sigma} d(FS_{EC_j}, FS_{min}} \quad (3)$$

In view of the complexity of the actual situation and the advantages of linguistic variables, this paper proposes a method for determining the priority based on linguistic variables. This method has the following characteristics: Firstly, it allows for a more comprehensive evaluation of the correlation strength of engineering features and customer needs given by members. There can be a positive correlation, no correlation, or a negative correlation between customer needs and engineering features, which ensures the rationality of the conclusion. Secondly, the weight of each evaluation member is fully considered when the linguistic variables are collected, which prevents biases and ensures the fairness of the evaluation information.

3. Application examples

Company A is a dust collector manufacturer in western China, and LMC long bag low-pressure pulse dust collector is its leading product, which is not only used in the traditional cement industry, but also in the electric power, chemical, metallurgy, steel, and other industries. The company faced less competition when it was first established. However, in recent years, similar products have emerged and customers have become more particular about their needs, which have greatly affected the company's market share. To retain its position in the market, the company decided to innovate products and reflect customer needs into their products. The company introduced the QFD method as an important strategic means to maintain and enhance its product competitive advantage.

Step 1: The project leader invited 5 members to form a QFD evaluation team. They were tasked to select customer requirements and determine the priority of engineering features. The team was composed of 2 members from the research and development department, 2 members from the production department, and 1 member from the marketing department. In the early stage of the new product design, the QFD team determined the customer needs in the house of quality through a questionnaire survey and group discussions. The customer needs were mainly as follows: efficient dust removal, low energy consumption, easy operation and maintenance, high stability and reliability, small space utilization, good performance, and long service life of filter bag and pulse valve. The technical department of the enterprise configured the engineering features the relevant engineering features are treatment air volume, filter bag performance, total filter area, air leakage rate, total equipment weight, bag cage structure, and dust concentration at the outlet. The project leader invited 6 customer representatives from the target market to form an assessment team for the determination of demand priority. The person in charge explained the content of the project and the tasks that the members were required to complete. Each evaluation member voted using linguistic variables, and the importance and competitiveness of customer requirement by the customer representatives. TOPSIS thought was introduced to determine the basic importance and competitiveness of each customer requirements, and the importance of each customer requirement was obtained as follows:

GIR = (0.256, 0.048, 0.029, 0.079, 0.169, 0.348, 0.071).

Step 2: In the process of determining the initial importance of engineering features, due to the differences in knowledge structure and work experience, the linguistic variables were directly used to evaluate the correlation between engineering features and customer needs, and evaluation matrices of strength of association was built, which are shown in **Tables 1–5**.

Table 1. Evaluation matrix of strength of association between customer requirements and engineering features given by ES_1

	CR$_1$	**CR$_2$**	**CR$_3$**	**CR$_4$**	**CR$_5$**	**CR$_6$**	**CR$_7$**
EC_1	$FS_{4/3}$	$FS_{1/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	$FS_{4/3}$
EC_3	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-4/3}$	$FS_{1/3}$	$FS_{1/3}$
EC_4	$FS_{4/3}$	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_5	$FS_{4/3}$	$FS_{4/3}$	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{-4/3}$	FS_0	FS_0
EC_6	$FS_{4/3}$	FS_3	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$	$FS_{1/3}$	$FS_{4/3}$
EC_7	FS_3	FS_3	FS_0	FS_0	FS_0	$FS_{1/3}$	FS_0

Table 2. Evaluation matrix of strength of association between customer requirements and engineering features given by ES_2

	CR$_1$	**CR$_2$**	**CR$_3$**	**CR$_4$**	**CR$_5$**	**CR$_6$**	**CR$_7$**
EC_1	FS_3	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	$FS_{1/3}$	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	$FS_{4/3}$
EC_3	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	$FS_{1/3}$
EC_4	$FS_{4/3}$	$FS_{4/3}$	FS_0	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$
EC_5	$FS_{4/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-4/3}$	FS_0	FS_0
EC_6	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	FS_3	$FS_{1/3}$	$FS_{1/3}$	$FS_{4/3}$
EC_7	$FS_{4/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{4/3}$	FS_0

Table 3. Evaluation matrix of strength of evaluation between customer requirements and engineering features given by ES_3

	CR$_1$	**CR$_2$**	**CR$_3$**	**CR$_4$**	**CR$_5$**	**CR$_6$**	**CR$_7$**
EC_1	$FS_{4/3}$	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	FS_3
EC_3	$FS_{4/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$
EC_4	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_5	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	FS_0	FS_0
EC_6	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	FS_3	$FS_{1/3}$	FS_3	$FS_{4/3}$
EC_7	$FS_{4/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{4/3}$	FS_0

Table 4. Evaluation matrix of strength of evaluation between customer requirements and engineering features given by ES_4

	CR_1	**CR_2**	**CR_3**	**CR_4**	**CR_5**	**CR_6**	**CR_7**
EC_1	FS_3	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	FS_3
EC_3	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{4/3}$
EC_4	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_5	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	FS_0	FS_0	FS_0
EC_6	$FS_{4/3}$	$FS_{4/3}$	$FS_{-4/3}$	$FS_{4/3}$	$FS_{1/3}$	FS_3	$FS_{1/3}$
EC_7	$FS_{1/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{1/3}$	FS_0

Table 5. Evaluation matrix of strength of association between customer requirements and engineering features given by ES_5

	CR_1	**CR_2**	**CR_3**	**CR_4**	**CR_5**	**CR_6**	**CR_7**
EC_1	FS_3	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{4/3}$	FS_3
EC_3	$FS_{4/3}$	$FS_{4/3}$	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$
EC_4	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{-4/3}$	FS_0	$FS_{1/3}$	FS_0
EC_5	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	FS_0	FS_0
EC_6	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$	FS_3	$FS_{1/3}$
EC_7	$FS_{1/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{4/3}$	FS_0

Step 3: According to the compromise voting method, the relative importance of the 5 evaluation members was found to be . The strength of association evaluation information given by the evaluation members was aggregated using Equation (1) to obtain the group evaluation matrix of the QFD team (**Table 6**).

Table 6. Group evaluation matrix of strength of association between customer requirements and engineering features

	CR_1	**CR_2**	**CR_3**	**CR_4**	**CR_5**	**CR_6**	**CR_7**
EC_1	$FS_{2.432}$	$FS_{0.735}$	$FS_{-0.129}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	$FS_{0.075}$	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{0.496}$	$FS_{2.270}$
EC_3	$FS_{0.895}$	$FS_{1.141}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{0.895}$	$FS_{0.978}$
EC_4	$FS_{0.771}$	$FS_{4/3}$	FS_0	$FS_{-0.928}$	$FS_{-0.279}$	$FS_{0.558}$	FS_0
EC_5	$FS_{4/3}$	$FS_{0.934}$	$FS_{-0.546}$	$FS_{-1/3}$	$FS_{-0.963}$	FS_0	FS_0
EC_6	$FS_{1.108}$	$FS_{1.185}$	$FS_{-1/3}$	$FS_{1.980}$	$FS_{1/3}$	$FS_{0.895}$	$FS_{0.978}$
EC_7	$FS_{2.280}$	FS_3	FS_0	FS_0	FS_0	$FS_{0.928}$	FS_0

Step 4: The group evaluation information of the priority of each engineering feature was obtained using Equation (2) as follows:

$FS_{EC1} = FS_{1.036,} FS_{EC2} = FS_{0.468,} FS_{EC3} = FS_{0.572,} FS_{EC4} = FS_{0.335,} FS_{EC5} = FS_{0.181,} FS_{EC6} = FS_{0.923,} FS_{EC7} = FS_{1.051.}$

Step 5: The priority of each engineering characteristic was obtained through Equation (3) as follows:

$gfp_1 = 0.157$, $gfp_2 = 0.136$, $gfp_3 = 0.140$, $gfp_4 = 0.130$, $gfp_5 = 0.124$, $gfp_6 = 0.153$, $gfp_7 = 0.158$.

The order of priority of engineering features was $EC_7 > EC_1 > EC_6 > EC_3 > EC_2 > EC_4 > EC_5$. The dust concentration at the outlet and the treatment air volume had a greater impact on customer requirements. Therefore, these two features should be prioritized during the product development and planning stage.

5. Conclusion

The method of determining the priorities of engineering features proposed in this paper facilitated the collection of accurate information on the correlation strength between customer requirements and engineering features. With this method, the evaluation members within the enterprise had a better understanding of engineering features, and thus, the determined linguistic variables were used to obtain the priority of engineering features by aggregating the relative importance of the evaluation members and the priority of customer requirements. This method was proven to be feasible by using it to determine the priority of each feature of the dust collector of Company A.

Disclosure statement

The author declares no conflict of interest.

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