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The Customer Requirements Analysis Method of Engineering Products Based on Multiple Preference Information

Guo Mao*

Nanbu County Discipline Inspection Commission, Nanchong 637000, Sichuan Province, China

***Corresponding author:** Guo Mao, wzqlinger@163.com

Abstract: To effectively evaluate the fuzziness of the market environment in product planning, a customer requirements analysis method based on multiple preference information is proposed. Firstly, decision-makers use a preferred information form to evaluate the importance of each customer requirement. Secondly, a transfer function is employed to unify various forms of preference information into a fuzzy complementary judgment matrix. The ranking vector is then calculated using row and normalization methods, and the initial importance of customer requirements is obtained by aggregating the weights of decision members. Finally, the correction coefficients of initial importance and each demand are synthesized, and the importance of customer requirements is determined through normalization. The development example of the PE jaw crusher demonstrates the effectiveness and feasibility of the proposed method.

Keywords: Product planning; Customer requirements; Importance ratings; Multi-format information

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1. Introduction

Nowadays, enterprises' market environments are increasingly influenced by technological innovation and rapid shifts in customer requirements. Enterprises are recognizing the paramount importance of researching and designing products that not only meet current customer needs but also anticipate future demands. However, the research and development of new products entail knowledge from multiple fields and pose numerous functional challenges, rendering the process highly complex. Quality Function Deployment (QFD) emerges as a systematic method for integrating customer requirements into the technical characteristics of the final product [1]. Primarily focusing on product development, quality management, and customer requirements analysis, QFD assists design teams in creating high-quality products that either meet or surpass customer expectations.

The initial hallmark of a successful new product design lies in its ability to satisfy end customers' needs. Therefore, ensuring the effective implementation of QFD necessitates identifying the product's market demand. Given the resource constraints faced by enterprises, it is imperative to evaluate the importance of each demand. The analysis of requirement importance serves as a pivotal step in the QFD process and significantly influences the subsequent setting of engineering feature target values.

The investigation into the importance of customer requirements has garnered attention from scholars both domestically and abroad. Early analysis methods, such as the 1–5 or 1–7 scoring method [2], typically involved obtaining scores for customer requirements importance through market surveys. However, these surveys often resulted in customers assigning high scores to every demand, thereby complicating the implementation of this method. Subsequently, the Analytic Hierarchy Process (AHP) was introduced to determine the importance of customer requirements [3]. Yet, customers' opinions often exhibit vagueness and uncertainty, leading to ambiguities. Consequently, fuzzy theory was integrated into network analysis [4]. To effectively capture the fuzziness of judgment, the newly developed linguistic theory was adopted, requiring decision-makers to employ linguistic variables to represent subjective and uncertain information in QFD [5].

Most real QFD processes involve teamwork. However, the methods proposed in the aforementioned research results typically require decision-makers to provide singular information, such as digital scale, pairwise comparison matrix, or linguistic variables. Moreover, decision-makers hail from diverse cultural backgrounds, possess varying education levels and work experiences, and inevitably exhibit differing judgment abilities. Consequently, it is challenging for product development and design decision-makers to utilize the same information to make judgments; they often prefer to employ their own preferences or familiar information to denote the importance of customer needs. While allowing decision-makers to freely choose the form of preference information complicates the QFD process, it undoubtedly represents a more realistic scenario. Therefore, studying customer requirements analysis methods capable of handling multiple preference information holds immense significance for the successful implementation of QFD.

2. The customer requirements analysis method

During the product development and design process, decision-makers often utilize various forms of preference information to express their individual perspectives, influenced by factors such as their level of knowledge, judgment abilities, and the objective environment. To streamline group decision-making processes, it becomes imperative to consolidate the aforementioned information. Research indicates that directly converting fuzzy complementary judgment matrices and reciprocal judgment matrices into interval numbers poses challenges. However, interval numbers, uncertain linguistic variables, reciprocal judgment matrices, and fuzzy complementary judgment matrices can be uniformly transformed into either fuzzy complementary judgment matrices or reciprocal judgment matrices. This paper opts for the use of fuzzy complementary judgment matrices. This decision stems from the fact that pair comparisons are employed to transform interval numbers and uncertain linguistic variables, thereby ensuring minimal loss of decision information.

Step 1: In the initial stage of product development, the project leader convenes relevant personnel from various departments to form a QFD team. This team collects product demand information through methods such as questionnaire surveys, field observations, and focused interviews, subsequently organizing and analyzing this dispersed information using tree graphs to delineate the product demand item set. During the information-gathering process, the QFD team must select customer representatives from the target market to constitute a decision-making group and participate in determining the importance of customer requirements. This paper refines the compromise voting method to ascertain the weight of each decision-making member.

Step 2: Decision-makers express their opinions in their preferred or more familiar forms of information. Utilizing **Equations (1)**, **(2)**, and **(3)**, interval numbers, uncertain linguistic variables, and fuzzy reciprocal judgment matrices are uniformly transformed, culminating in the generation of fuzzy complementary judgment matrices for decision-makers.

$$b_{i_1i_2} = min\left\{max\left(\frac{q_{i_1}^u - q_{i_2}^l}{q_{i_1}^u - q_{i_1}^l + q_{i_2}^u - q_{i_2}^l}, 0\right), 0\right\} \tag{1}$$

$$b_{i_1i_2} = max\left\{1 - max\left(\frac{y_{i_1}^u - y_{i_2}^l}{y_{i_1}^u - y_{i_1}^u + y_{i_2}^u - y_{i_2}^l}, 0\right), 0\right\} \tag{2}$$

$$b_{i_1i_2} = 0.5 + \log_c f_{i_1i_2} \tag{3}$$

Step 3: To facilitate the aggregation of decision information, it is essential to determine the ordering method of the fuzzy complementary judgment matrix. The order vector of each matrix can be directly obtained from the fuzzy complementary judgment matrix using the row and normalization method. This approach is simple and convenient in the actual calculation process, enabling the full utilization of the important evaluation information of each customer requirement. The ordering vector of the fuzzy complementary judgment matrix is determined by **Equation (4)**, and subsequently, the group decision matrix of the initial importance of customer requirements is constructed.

$$\varphi_{i_1} = \frac{\sum_{i_2=1}^{m} b_{i_1i_2} + \frac{m}{2} - 1}{m(m-1)} \tag{4}$$

Step 4: During the actual QFD process, only members of the decision-making group can adequately express their opinions to ensure the rationality and accuracy of the results. Considering the differing knowledge structures and experiences of members, the heterogeneity of decision-making members must be taken into account during the customer requirements importance analysis. The initial importance vector of customer requirements is derived by aggregating the weight of the decision-maker and group decision matrix using the weighted average operator.

Step 5: Through Kano questionnaire surveys, the Kano-type correction coefficients of each customer requirement are obtained. After determining the type of customer requirements, QFD members leverage their R&D and design abilities and experience in alignment with the current market situation and development trends. They assign the Kano coefficient of the relevant type and obtain the correction vector of the importance of customer requirements by aggregating the initial importance vector of customer requirements and the corresponding Kano coefficient using **Equation (5)**.

$$me_i = be_i \times KA_k \tag{5}$$

Step 6: The revised importance of customer requirements is normalized. **Equation (6)** is utilized to calculate the standardized importance of each customer requirement. Based on the standardized importance, each customer requirement is ranked to determine the allocation of resources.

$$gme_i = \frac{me_i}{\sum_{i=1}^{m} me_i} \tag{6}$$

3. Application examples

Company H is dedicated to establishing China's largest complete set of sand equipment manufacturing bases and has successfully developed a range of products, including jaw crushers, cone crushers, straight-through crushers, impact crushers, vertical shaft crushers, spiral sand washing machines, belt conveyors, vibration sorting screens, and feeding machines, totaling over 80 different products. Among these products, the PE jaw crusher stands out as a special equipment for construction sand production. Widely utilized and boasting performance levels reaching international standards, it serves as the primary crushing equipment of choice. To maintain a leading position in the long-term competition, the market demands higher standards for the PE jaw crusher. Therefore, new product development and production must take into account the diverse needs of customers, offering customized designs and production accordingly.

Step 1: The QFD team comprises five employees from various corporate departments, including two R&D and design staff, two production staff, and one marketing staff member. In the project's preparation phase, the company conducted comprehensive market research and in-depth interviews. Based on this, the QFD team identified the customer needs for the PE jaw crusher: high crushing yield, low operating costs, superior product granularity, adaptability, high equipment flexibility, and minimal noise levels. Selecting six customers from the target market as decision-making members, the enterprise tasked them with determining the importance of these customer needs. Each of the six decision-makers assessed the familiarity of the other members with product development and design according to their own preferences. Utilizing the compromise voting method, the weight of each decision-making member was determined as follows: $\rho = (0.241,0.144,0.212,0.128,0.146,0.129)$.

Step 2: During the evaluation process of the initial importance of each customer requirement, significant differences in the cultural backgrounds and work experiences of the decision-makers led them to prefer various forms of information for evaluation. The evaluation results provided by the six decision-makers are as follows:

$$Q^1 = ([0.214,0.226],[0.159,0.173],[0.205,0.218],[0.204,0.211],[0.150,0.166],[0.145,0.161])^T$$

$$B^2 = \begin{bmatrix} 0.50 & 0.72 & 0.63 & 0.57 & 0.76 & 0.88 \\ 0.28 & 0.50 & 0.41 & 0.44 & 0.50 & 0.63 \\ 0.37 & 0.59 & 0.50 & 0.50 & 0.60 & 0.65 \\ 0.43 & 0.56 & 0.50 & 0.50 & 0.69 & 0.74 \\ 0.24 & 0.50 & 0.40 & 0.31 & 0.50 & 0.56 \\ 0.12 & 0.37 & 0.35 & 0.26 & 0.44 & 0.50 \end{bmatrix}$$

$$L^3 = ([S_{4/3},S_3],[S_0,S_{1/3}],[S_{1/3},S_{4/3}],[S_{1/3},S_{4/3}],[S_0,S_{1/3}],[S_{-1/3},S_0])^T$$

$$B^4 = \begin{bmatrix} 0.50 & 0.75 & 0.64 & 0.61 & 0.62 & 0.86 \\ 0.25 & 0.50 & 0.49 & 0.43 & 0.54 & 0.68 \\ 0.36 & 0.51 & 0.50 & 0.50 & 0.58 & 0.63 \\ 0.39 & 0.57 & 0.50 & 0.50 & 0.65 & 0.73 \\ 0.38 & 0.46 & 0.42 & 0.35 & 0.50 & 0.58 \\ 0.14 & 0.32 & 0.37 & 0.27 & 0.42 & 0.50 \end{bmatrix}$$

$$Q^5 = ([0.199,0.211],[0.162,0.183],[0.207,0.215],[0.202,0.213],[0.156,0.169],[0.139,0.147])^T$$

$$F^6 = \begin{bmatrix} 1 & 5 & 1/2 & 2 & 4 & 7 \\ 1/5 & 1 & 1/5 & 1/3 & 2 & 3 \\ 2 & 5 & 1 & 1/2 & 3 & 8 \\ 1/2 & 3 & 2 & 1 & 4 & 6 \\ 1/4 & 1/2 & 1/3 & 1/4 & 1 & 2 \\ 1/7 & 1/3 & 1/8 & 1/6 & 1/2 & 1 \end{bmatrix}$$

According to **Equations (1)**, **(2)**, and **(3)**, the above information is transformed into the form of a fuzzy complementary judgment matrix, and the judgment matrix after the consistency of each decision member can be obtained:

$$B^1 = \begin{bmatrix} 0.50 & 1.00 & 0.84 & 1.00 & 1.00 & 1.00 \\ 0.00 & 0.50 & 0.00 & 0.00 & 0.77 & 0.93 \\ 0.16 & 1.00 & 0.50 & 0.70 & 1.00 & 1.00 \\ 0.00 & 1.00 & 0.30 & 0.50 & 1.00 & 1.00 \\ 0.00 & 0.23 & 0.00 & 0.00 & 0.50 & 0.66 \\ 0.00 & 0.07 & 0.00 & 0.00 & 0.34 & 0.50 \end{bmatrix}$$

$$B^3 = \begin{bmatrix} 0.50 & 1.00 & 1.00 & 1.00 & 1.00 & 1.00 \\ 0.00 & 0.50 & 0.00 & 0.00 & 0.50 & 1.00 \\ 0.00 & 1.00 & 0.50 & 0.50 & 1.00 & 1.00 \\ 0.00 & 1.00 & 0.50 & 0.50 & 1.00 & 1.00 \\ 0.00 & 0.50 & 0.00 & 0.00 & 0.50 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.50 \end{bmatrix}$$

$$B^5 = \begin{bmatrix} 0.50 & 1.00 & 0.20 & 0.39 & 1.00 & 1.00 \\ 0.00 & 0.50 & 0.00 & 0.00 & 0.79 & 1.00 \\ 0.80 & 1.00 & 0.50 & 0.68 & 1.00 & 1.00 \\ 0.61 & 1.00 & 0.32 & 0.50 & 1.00 & 1.00 \\ 0.00 & 0.21 & 0.00 & 0.00 & 0.50 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.50 \end{bmatrix}$$

$$B^6 = \begin{bmatrix} 0.50 & 0.86 & 0.34 & 0.66 & 0.82 & 0.97 \\ 0.14 & 0.50 & 0.09 & 0.25 & 0.66 & 0.75 \\ 0.66 & 0.91 & 0.50 & 0.34 & 0.75 & 1.00 \\ 0.34 & 0.75 & 0.66 & 0.50 & 0.82 & 0.94 \\ 0.18 & 0.34 & 0.25 & 0.18 & 0.50 & 0.66 \\ 0.03 & 0.25 & 0.00 & 0.06 & 0.34 & 0.50 \end{bmatrix}$$

Step 3: According to **Equation (4)**, the ordering vectors of each fuzzy complementary judgment matrix are calculated respectively, and the customer requirements group decision matrix can be constructed accordingly, as shown in **Table 1**.

Table 1. Group decision matrix of initial importance of customer needs

0.245	0.140	0.212	0.193	0.113	0.097
0.202	0.159	0.174	0.181	0.150	0.135
0.250	0.133	0.200	0.200	0.133	0.083
0.199	0.163	0.169	0.178	0.156	0.134
0.203	0.143	0.233	0.214	0.124	0.083
0.205	0.146	0.205	0.200	0.137	0.106

Step 4: The weight information of each decision member is aggregated to obtain the initial importance vector of customer requirements as BE = (0.223, 0.145, 0.201, 0.195, 0.132, 0.103).

Step 5: Kano correction factors for each customer requirements category are determined through comprehensive market research. With reference to historical data, three types of Kano coefficients were determined: KA_1 = 0.8, KA_2 = 1.0, and KA_3 = 1.5. The revised customer requirements importance vector is calculated by **Equation (5)** as ME = (0.178, 0.218, 0.161, 0.195, 0.132, 0.103).

Step 6: The standardized importance of customer requirements can be obtained by using **Equation (6)** as gme_1 = 0.180, gmi_2 = 0.221, gmi_3 = 0.163, gmi_4 = 0.198, gmi_5 = 0.134, and gmi_6 = 0.104.

4. Conclusion

Customer requirements analysis in product planning constitutes a group decision-making process. Recognizing the complexity and uncertainty inherent in the market environment, this paper introduces a customer requirements analysis method based on multiple preference information. The method integrates four potential preference information sources: interval numbers, uncertain linguistic variables, reciprocal judgment matrices, and fuzzy complementary judgment matrices. By employing different conversion functions, the method ensures the comprehensive consideration of decision-makers' weight information, harmonizing it into a uniform format. Moreover, the initial importance of customer requirements undergoes modification in accordance with the Kano model. The approach proposed in this paper is characterized by its simplicity and ease of operation. It effectively accommodates the heterogeneity of decision-makers and the inherent uncertainty in their judgments, allowing for the scientific utilization of the judgment information provided by decision-makers.

Disclosure statement

The author declares no conflict of interest.

References

[1] Wang ZQ, Chen ZS, Garg H, et al., 2022, An Integrated Quality-Function-Deployment and Stochastic-Dominance-Based Decision-Making Approach for Prioritizing Product Concept Alternatives. Complex & Intelligent Systems, 8: 2541–2556. https://doi.org/10.1007/s40747-022-00681-1

[2] Sen K, Ghosh S, Sarkar B, 2019, Evaluation Strategy of Hydraulic Crane Through Mathematical Programming: An Automated Approach to Meet Customer Requirement. Journal of The Institution of Engineers (India): Series C, 100: 647–664. https://doi.org/10.1007/s40032-019-00523-z

[3] Dong C, Yang Y, Chen Q, et al., 2022, A Complex Network-Based Response Method for Changes in Customer Requirements for Design Processes of Complex Mechanical Products. Expert Systems with Applications, 199: 117124. https://doi.org/10.1016/j.eswa.2022.117124

[4] Shi Y, Peng Q, 2021, Definition of Customer Requirements in Big Data Using Word Vectors and Affinity Propagation Clustering. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 235(5): 1279–1291. https://doi.org/10.1177/0954408921100177

[5] Wang Z, Fung RYK, Li Y-L, et al., 2018, An Integrated Decision-Making Approach for Designing and Selecting Product Concepts Based on QFD and Cumulative Prospect Theory. International Journal of Production Research, 56(5): 2003–2018. https://doi.org/10.1080/00207543.2017.1351632