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# Dynamic Analysis of Customer Demand Based on Intuitionistic Fuzzy Number in Product Planning

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**Abstract:** To address the fuzziness and variability in determining customer demand importance, a dynamic analysis method based on intuitionistic fuzzy numbers is proposed. First, selected customers use intuitionistic fuzzy numbers to represent the importance of each demand. Then, the preference information is aggregated using customer weights and time period weights through the intuitionistic fuzzy ordered weighted average operator, yielding a dynamic vector of the subjective importance of the demand index. Finally, the feasibility of the proposed method is demonstrated through an application example of a vibrating sorting screen.

**Keywords:** Quality function deployment; Customer demand; Intuitionistic fuzzy number; Dynamic analysis method

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## 1. Introduction

Quality Function Deployment (QFD) is a method used to capture customer expectations or demands in the products or services offered by enterprises, covering key stages such as research and development, design, and production [1]. It has been successfully implemented across many industries and has become a systematic tool for manufacturing enterprises to improve products or develop new ones. QFD is a design method driven by customer expectations or demands, with the House of Quality as an important tool for realizing this core concept. The House of Quality allows customer expectations or voices to be communicated directly into the product design process and displayed in an intuitive matrix. However, the accurate construction of the House of Quality faces a significant challenge—how to conduct a reasonable analysis of previous research information in the ever-changing market, as customer demands for products vary over time. Addressing these changing demands is the main focus of this paper.

Traditional demand analysis methods typically assess customer satisfaction at a particular point in time, overlooking the dynamic changes in demand, which may result in products that fail to meet customer

expectations and lead to a significant waste of resources and time. Although neural networks have been used to analyze and predict the importance of customer demands, the large amount of actual data required poses a significant challenge [2]. The Grey GM (1,1) model has been used to predict future demands due to its simplicity and lower data requirements, making it one of the most commonly used models [3]. However, this model relies on data obtained through expert scoring, which reduces the credibility and accuracy of the conclusions. To address the uncertainty and fuzziness in demand importance analysis, fuzziness should be fully represented [4]. Intuitionistic fuzzy numbers provide a way to express customer opinions, ensuring that the preference information remains intact during processing, thus avoiding the loss of decision-making information while maximizing the use of customer input.

In summary, traditional demand analysis methods tend to focus on current demand and rarely consider the dynamic nature of demand indicators. While some studies have addressed the dynamic nature of demands, they have not incorporated the fuzzy information inherent in human judgment during demand determination. Therefore, this paper proposes a dynamic analysis method for customer demands based on intuitionistic fuzzy numbers, analyzing changes in demand importance throughout the product life cycle and applying the method to a product design example from a machinery manufacturing enterprise.

## 2. Dynamic analysis of customer demand importance

The key factor in the QFD method is identifying the correct target market and satisfying the needs of the final customers. Therefore, determining the importance of customer needs greatly influences the subsequent decisions regarding product planning [5]. During the early stages of product development, the project leader organizes market research and gathers customer demand indicators for product development through on-site inquiries, observations, the completion of demand questionnaires, and in-depth discussions with key customers. The enterprise randomly selects certain evaluation indicators of customer participation demand from the target market. To differentiate the influence levels of various customers, personnel from relevant departments, such as marketing and after-sales service, conduct pairwise comparisons of the customers involved in the evaluation to determine the weight vector.

The success of product improvement also depends on the ability to understand and respond to customers' ever-changing needs. To develop and design customer-oriented products or services, enterprises must conduct timely market research throughout the development process and capture rapidly evolving information and data. To fully reflect the diversity and dynamics of customer needs, the QFD team responsible for the project planned a detailed and comprehensive survey, which was conducted during representative time periods. The time periods for the survey are determined by the QFD team based on the characteristics of the product and target market. The relative comparison method is then used to obtain the influence degree vector for each time period based on market similarity.

In the initial stages of product development and design, obtaining accurate information and data can be challenging. The limited accuracy of the initial information can impact the credibility of conclusions. To enhance the reliability and precision of the findings, this study invited selected customers to use intuitionistic fuzzy numbers to provide preference information regarding the subjective importance of each customer demand. Customers evaluate various demand indicators during specific periods based on their experience with existing products. As a result, an evaluation matrix for the subjective importance of customer demand indicators

is constructed.

Suppose a selected customer uses intuitionistic fuzzy numbers to represent the subjective importance evaluation value of a demand indicator during a given time period. Using the intuitionistic fuzzy ordered weighted average operator, **Equation (1)** aggregates the weight vector of the selected customer and the subjective importance evaluation matrix of the demand indicator, producing a comprehensive evaluation matrix for the subjective importance of the customer demand indicator.

$$c\hat{r}_{hi} = \mathrm{IFIOWA}_{\boldsymbol{\omega}}\left[\left(CU_1, \hat{r}_{hi}^1\right), \left(CU_2, \hat{r}_{hi}^2\right), \ldots, \left(CU_n, \hat{r}_{hi}^n\right)\right] = \sum_{j=1}^{n} \omega_j \hat{b}_{hi}^j = \left(1 - \prod_{j=1}^{n}\left(1 - \mu_{hi(b)}^j\right)^{\omega_j}, \quad 1 - \prod_{j=1}^{n} \nu_{hi(b)}^{j\ \omega_j}\right) \tag{1}$$

Based on the intuitionistic fuzzy ordered weighted average operator, the comprehensive evaluation value of the subjective importance of the demand indicator over a time period is determined. **Equation (2)** is then used to aggregate the comprehensive evaluation matrix of the subjective importance of the demand indicator, resulting in a dynamic vector for the subjective importance of the customer demand indicator.

$$DCI_i = \mathrm{IFIOWA}_{\boldsymbol{\rho}}\left[\left(PT_1, c\hat{r}_{1i}\right), \left(PT_2, c\hat{r}_{2i}\right), \ldots, \left(PT_l, c\hat{r}_{li}\right)\right] = \sum_{h=1}^{l} \rho_h f_{hi} = \left(1 - \prod_{h=1}^{l}\left(1 - \phi_{hi(f)}\right)^{\rho_h}, \quad 1 - \prod_{h=1}^{l} \varphi_{hi(f)}^{\ \rho_h}\right) \tag{2}$$

**Equation (3)** calculates the subjective dynamic value of the demand indicator. Finally, the standardized dynamic vector of the subjective importance of each customer demand indicator is obtained using **Equation (4)**.

$$sv_i = \left(1 - \prod_{h=1}^{l}\left(1 - \phi_{hi(f)}\right)^{\rho_h}\right) - \left(1 - \prod_{h=1}^{l} \varphi_{hi(f)}^{\ \rho_h}\right) \tag{3}$$

$$NDCI_i = \frac{sv_i + 0.5}{\sum_{i=1}^{m}(sv_i + 0.5)} \tag{4}$$

## 3. Application examples

A machinery manufacturing enterprise, primarily engaged in the production of complete sets of sand and gravel equipment and mine crushers, derives a significant portion of its total sales revenue from vibrating sorting screens. These screens are widely used in industries such as mining, building materials, transportation, energy, and chemicals for product classification. Recently, the enterprise has invested nearly 100 million Chinese yuan to upgrade its modern production line and for product research and development. The QFD method has become a strategic tool for the company to consolidate and expand its competitive advantage, with the improvement of the vibrating sorting screen being one of its key goals.

Step 1: The enterprise selected relevant personnel from the sales, product research and development, production, and quality supervision departments to form a QFD team for product development. Based on market research and field observations, the QFD team identified that customers were most concerned about the following demand indicators: stronger processing capacity, higher screening efficiency, greater reliability of the screening bed, easier maintenance, and longer service life. Customers were classified according to regional and historical data, and six customers were selected to participate in the evaluation of demand importance. The

weight vector for these six customers was determined using the pairwise comparison method, resulting in the following vector: .

Step 2: To maintain a competitive advantage, the company developed a long-term research plan. Through product and market analysis, the collection of market information and data was organized as follows: (1) At the market entry stage, when existing products first enter the market, it is crucial for the enterprise to gather customer feedback; (2) During the product development stage, as customers become more familiar with the product and market share increases; (3) At the mature product stage, when sales growth begins to slow, and competition becomes more intense; (4) In the new product development stage, when sales of older products decline and customer satisfaction fluctuates. The QFD team conducted pairwise comparisons of the research periods based on market similarity and derived the influence degree vector for different time periods as follows: $\rho$ = (0.285, 0.214, 0.227, 0.274).

Step 3: During the product development and design stages, it is challenging to obtain precise information and data, making the use of intuitionistic fuzzy numbers appropriate for judgment. Each customer provides preference information regarding the importance of various demand indicators based on the product's characteristics and their specific requirements.

Step 4: **Equation (1)** is used to aggregate the weight vector of the selected customers and the importance evaluation matrix of the demand index to obtain the comprehensive evaluation matrix of the subjective importance of the customer demand index (**Table 1**).

**Table 1.** Comprehensive evaluation matrix of the dynamic importance of customer demand

| | $CI_1$ | $CI_2$ | $CI_3$ | $CI_4$ | $CI_5$ |
|---|---|---|---|---|---|
| $PT_1$ | (0.525,0.359) | (0.593,0.318) | (0.523,0.346) | (0.425,0.364) | (0.307,0.575) |
| $PT_2$ | (0.609, 0.271) | (0.612,0285) | (0.521,0.261) | (0.492,0.367) | (0.387,0.475) |
| $PT_3$ | (0.672,0.221) | (0.672,0.211) | (0.600, 0.227) | (0.492,0.477) | (0.537,0.342) |
| $PT_4$ | (0.658,0.261) | (0.628,0.239) | (0.571,0.262) | (0.520,0.342) | (0.492,0.443) |

Step 5: **Equation (2)** is then used to aggregate the influence degree vectors of different time periods and the comprehensive evaluation matrix of the subjective importance of demand indicators. This calculation yields the dynamic evaluation value of the subjective importance of each customer demand indicator. Finally, the normalized dynamic vector of the subjective importance of the customer demand index is calculated using **Equation (4)** as follows: .

## 4. Conclusion

Traditional methods for determining the importance of customer demand only analyze existing information from a specific period, which can lead to significant errors in decision-making. The dynamic analysis method proposed in this paper allows improved products to better meet the evolving needs of customers. By fully utilizing market research data and the evaluation capabilities of customer representatives, the intuitionistic fuzzy-ordered weighted average operator is applied to calculate the importance of customer needs. This approach ensures the accuracy and credibility of the input information for the House of Quality.

## Disclosure statement

The authors declare no conflict of interest.

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