A Method for Determining the Importance of Customer Demand Based on Rough Set and DEA

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Abstract—**Affected by customers' lack of experiences and personal preferences, the importance of customer demand as 0 by only using Rough Set method frequently occurs. Existing methods could not determine this importance of indicators, so it is usually deleted. A new method combining Rough Set and Data Envelopment Analysis (DEA) to determine importance of customer demand in Quality Function Deployment (QFD) is proposed. Based on Rough Set theory, we modify the importance as 0 to determine the fundamental importance of customer demand by combining customers' preferences and experts' experiences. Let customer demand be decision-making unit, competitive differences and other factors the input and output indicators, which give full play to DEA's advantages of avoiding subjective factors and reducing errors to obtain relative efficiency of pure technical indicators. Final importance of customer demand is confirmed by combing fundamental importance with relative efficiency in QFD. Lastly, an application example is to illustrate the effectiveness of this method.**

Index Terms—**quality function deployment, rough set, data envelopment analysis, importance**

I. INTRODUCTION

In Quality Function Deployment (QFD), enterprises can make pointed design to improve customer satisfaction and market competitiveness by learning customer demand [1]. Obtaining the importance of customer demand is vital, which plays an important role in defining technical value and optimization of the House of Quality [2].

Traditional methods for determining customer demand include Analytic Hierarchy Process (AHP), Fuzzy Set and Rough Set [2, 9]. AHP provides a hierarchy structure of complex customer demand to facilitate decision-makers' analysis [3, 4]. For example, Zhang et al [5] improved AHP and proposed a method of the importance of customer demand based on Monte Carlo-AHP; Hu and Zhang [6] adopted fuzzy clustering to classify users' needs, and determined parameters in House of Quality by group-decision AHP. However, it requires customers' accurate and repeated information, which is time-consuming and could lead to the annoyance of customers.

Fuzzy Set theory enjoys advantages in language expression of customers [7-10]. Yang and Lin [11] introduced Fuzzy Set into QFD and discussed multi-semantic granularity of linguistic information. But Fuzzy set is subject to knowledge level of customers. It assumes that customers' cognition differs equally, which could not reflect real difference in perception. And its determination of membership function is mainly based on subjective judgment [12].

Rough Set theory digs out customers' real perception with no need of acquiring prior information, which draws great attention [13-15]. Li et al [13, 14] established a model acquiring the fundamental importance of customer demand based on Rough Set theory. Wang and Xiong [16] proposed a rough set AHP of customer demand importance in QFD to meet the quality demand of customers based on AHP and rough number and rough interval in Rough Set theory. Owing to the difference of customers' knowledge level and individual preferences, these studies neglect the significance when the importance of customer demand is 0 [14, 16, 17]. This demand is indispensable in production and it receives great attention from many customers. Simply using Rough Set to determine the importance of customer demand will lead to deviation. Thus, it is necessary to readjust the condition of the importance of customer demand as 0. Experts are endeavoring to compensate the shortcomings caused by customers and emphasize the rationality of the results.

Final importance of customer demand in QFD consists of fundamental importance and modifying factor. In the process of establishing product planning House of Quality, enterprises will modify some customers' competitive strength according to the human resource, technology and funds they invest to improve customer satisfaction as well as product competitiveness. Given the influences of factors like competitiveness assessment on the importance of customer demand, enterprises' modifying the importance of customer demand aim at reflecting the demands of enterprises and customers, and

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pressure of competitors. There are many researches focusing on modifying factor. Modifying factors proposed by some scholars not only fail to reflect the willing of enterprises to improve their products, but also fail to make the most of competitiveness assessment [7, 11]. Some researches take no consideration of the coupling relationship among modifying factors on the importance [14-16]. Most scholars modify factors from the perspective of competitiveness assessment only [14, 16-18]. However, customer demand is affected by many factors. Single assessment can not fully modify the fundamental importance. Thus, it is not reasonable to determine modifying factors in this way.

Based on Rough Set theory and expertise, we modify the situation where the importance of customer demand is 0, and determine the fundamental importance of customer demand. Meanwhile, DEA is adopted to calculate modifying factors, which enable us to minimize influences of subjective preferences. Let customer demand be decision-making unit, competitive differences and other factors the input and output indicators. Pure technical indicator relative efficiency obtained reflects ore accurately the willingness of enterprises to improve the products. Lastly, final importance of customer demand is determined by combining fundamental importance and relative efficiency in QFD.

II. Basic Theories

A. Determination of Importance of Customer Demand in QFD

Determination of importance of customer demand in QFD is based on information provided by customers and enterprises. In the process of establishing the House of Quality, procedures of determining importance are as follows [5, 6, 11, 12, 14-16].

(1) Customer demand is acquired trough surveys and investigation. Let it be $C_1, C_2, ..., C_n$.

(2) Relative importance of each demand is analyzed to acquire the fundamental importance, which is $g_i = (g_1, g_2, ..., g_n), i = 1, 2, ..., n$.

(3) Market competitiveness assessment is conducted. Assume there are $k-1$ competitive factories, $F_2, F_3, ..., F_k$, and n customer demand. $X = \{x_{ij}\}$ $(i = 1, ..., m; j = 1, ..., k)$ is competitive assessment matrix. Then, the vector of modifying factors could be got, which is $r_i = (r_1, r_2, ..., r_n)$, $i = 1, 2, ..., n$.

(4) Final importance of customer demand is obtained by g_i and r_i , which is $f = (f_1, f_2, ..., f_n)$.

B. Rough Set Theory

Rough Set theory is one of many methods that can be employed to analyze uncertain (including vague) systems, which is widely used in process control, data mining, decision making and so on. It is based on classified mechanism, which is an equivalence relation in certain space. This equivalence relation makes up the partition of space. And each set is called concept. It only uses the information presented within the given data [12-19]. The definition of knowledge expression system is as follows.

(1) $S = (U, A, V, f)$ is a knowledge expression system, where U is a non-empty set of finite objects; A is a non-empty, finite set of attributes; V is the set of values that attributes may take, and $f : U \times A \to V$ is the information function.

(2) R refers to an equivalence relation. $r \in R$, if $ind(R) = ind(R - \{r\})$, r is indiscernible in R. If $P = R - \{r\}$ is independent, P is a reduct of R.

(3) Let P and Q the equivalence relation in U , then

$$Pos_P(Q) = \bigcup_{x \in U/Q} \underline{P} X \tag{1}$$

(4) Let P and Q the equivalence relation in U , $R \in P$

$$Pos_{\text{Sin } d(P)}(ind(Q)) = Pos_{\text{Sin } d(P - \{R\})}(ind(Q)) \tag{2}$$

where R is unnecessary in P.

(5) $T = (U, A, C, D)$ is decision table, C is condition attribute, and D is decision attribute. D 's dependence on C is

$$\gamma = card(Pos_C(D)) / card(U) \tag{3}$$

The importance of attribute i, namely $\beta(i)$, is

$$\beta(i) = \gamma(C, D) - \gamma(C - \{a\}, D) \tag{4}$$

Rough Set theory can judge customers' real perception and the order of customer demand. However, regardless of customers' difference in background and knowledge, and the real significance of certain demand when the importance is 0, deviation occurs [14, 16, 17]. Therefore, expertise is needed to modify this deviation.

C. Data Envelopment Analysis

Data envelopment analysis (DEA) is a nonparametric method in operations research and economics for the estimation of production frontiers. It is used to empirically measure productive efficiency of decision making units. This approach has the benefit of avoiding subjective factors, simplifying calculation, minimize errors and so on. It is widely used in fields like management science, decision analysis and assessment. DEA is a linear programming methodology to measure the efficiency of multiple decision-making units (DMU) when the production process presents a structure of multiple inputs and outputs. It is able to accommodate a multiplicity of inputs and outputs, determining the most favorable weight and obtaining the relative efficiency of each DMU. Its assessment results avoid the influences of man-induced factors. Its C^2R model is as follows.

Assume there are n DMU, m input indicators and s output indicators in each DMU. Input and output vectors of the i-th DMU is X_i and Y_i respectively, $X_i = (x_{1i}, x_{2i}, ..., x_{mi})^T$, $Y_i = (y_{1i}, y_{2i}, ..., y_{si})^T$. These are acquired data. $v = (v_1, v_2, ..., v_m)^T$ is the weight vector of m input and $u = (u_1, u_2, ..., u_s)^T$ is the weight vector of s output. The two are variables. When $x_0 = x_{i0}, y_0 = y_{i0}$, $1 \le i0 \le n$.

$$C^2R\begin{cases}\max\dfrac{u^TY_0}{v^TX_0}=V^IP\\ \dfrac{U^TY_i}{V^TX_i}\le 1, i=1,2,...,n\\ u\ge 0, v\ge 0\end{cases} \quad (5)$$

DEA is an objective method of calculating relative efficiency with restrains as modifying factors, which compensates the weakness of other methods determining modifying factors [20-23].

III. Importance of Customer Demand Based on Rough Set and DEA

First, determine the factor set of customer demand. Questionnaire and investigation are employed to collect data for customer demand and satisfaction. Assume the customer demand set is $C_n=\{c_1,c_2,\cdots,c_i,\cdots,c_n\}$, customer satisfaction is $D=\{d_1,d_2,...,d_n\}$. Define the demand set as condition attribute set *AT*, customer satisfaction as decision attribute set d. Then a decision system can be obtained, $DT=(U,AT\cup\{d\})$.

Second, make and analyze the decision table. A decision table is made by Rosetta software based on the acquired data shown in Table 1. $C_1,...,C_n$ is condition attribute while *D* decision attribute. According to the calculation rules of rough set, roughness of this decision table is examined.

TABLE I.

Decision table

X	C_1	C_2	C_3	C_4	C_5	C_6	D
X_1	1	1	1	1	1	1	1
X_2	1	1	1	2	1	1	1
X_3	1	1	1	3	1	1	2
X_4	1	1	2	1	1	1	1
X_5	1	1	2	2	1	1	2
X_6	1	1	2	3	2	1	3
X_7	1	1	3	1	1	1	2
X_8	1	1	3	2	1	1	3
X_9	1	1	3	3	1	2	3
……	…	…	…	…	…	…	…

Reduction of each condition attribute and each object in the sample are studied to make judgment of the completeness of information base. As for the determination of the importance of attributes, we take a classification and compare the condition without this attribute. Make not all attributes as the baseline. Each classification is examined with the consideration of one attribute deleted. If this attribute affects the classification and decision after it is deleted, this attribute is important, and its importance is relatively larger, otherwise, smaller. Based on the above analysis, importance of each attribute in the decision table is selected as the measurement of fundamental importance of customer demand in QFD. According to (4) $\beta(i)=\gamma(C,D)-\gamma(C-\{a\},D)$, we can get the objective weight of customer demand:

$$g_i=\beta_i/\sum_{i=1}^{n}\beta_i,\ i=1,...,n \quad (6)$$

Third, acquire the fundamental importance of customer demand. As for the condition where the weight of customer demand is 0, the result acts as subjective weight which is assessed by expert team. Experience factor is introduced to reflect the preference for objective and subjective weight of customer demand. If the experience factor is bigger, expert team's experience is more prominent.

Fourth, determine the modifying factor of fundamental importance of customer demand. According to their reality, enterprises make assessment for capital, technology and human resources that can exert influence on customer demand to improve competitiveness and customer satisfaction. This, in fact, is a modification of fundamental importance, which is to be more real and more accurate in reflecting customer and enterprises demand. DEA is adopted to make each customer demand a DMU, and divide factors into input and output indicators. The smaller input data is, or the bigger output data is, the outcome is better. Equation (5) is changed into a linear programming model as (7).

$$\begin{aligned}&\min\theta\\ s.t.&\begin{cases}\sum_{i=1}^{n}X_i\lambda_i+S^-=\theta X_0, i=1,2,...,n\\ \sum_{i=1}^{n}Y_i\lambda_i-S^+=Y_0, i=1,2,...,n\\ \lambda_i\ge 0, i=1,2,...,n\\ S^-\ge 0, S^+\ge 0\end{cases}\end{aligned} \quad (7)$$

Where λ_i is the weight parameter of input and output indicators; S^- and S^+ are slack variables of input and output indicators respectively; θ is the assessment outcome of DMU_i. When θ=1, DMU is valid for DEA and its output reaches a maximum compared to input; When θ<1, DMU is valid for non-DEA and its output doesn't reach a maximum compared to input. Enterprises consider its customers' demand based on competitive evaluation and resources. Design and manufacturing capabilities is a kind of ability which enterprises can achieve this requirement, as the input indicator; competitiveness assessment indicator reflects the status of the competitiveness of the demand, as output indicators; plan improvement goal is a kind of expectation which enterprises hope to reach, as output indicators. Equation (7) is used to calculate relative efficiency of each DMU as a modifying vector $\theta_i=(\theta_1,\theta_2,...,\theta_n)(i=1,2,...,n)$, it can be obtained by Max DEA 5.2.

Fifth, calculate the final importance of customer demand. The final importance of each customer demand is calculated based on relative efficiency θ_i and fundamental importance obtained above, that is

$$B_i = \frac{\theta_i \times [\zeta \times g_i + (1-\zeta) \times \lambda_i]}{\sum_{i=1}^{n} \theta_i \times [\zeta \times g_i + (1-\zeta) \times \lambda_i]} (i = 1, 2, ..., n) \quad (8)$$

Where ζ is experience factor, λ is subjective weight and g_i objective weight.

IV. Case Applications

Procedure 1: questionnaire is carried out according to enterprises' Research and Design Department. There are 6 customer demand after factor analysis, C_1, C_2, C_3, C_4, C_5, C_6, and the level of customer satisfaction is D.

Procedure 2: analyze the acquired data and make a decision table shown as Table II.

TABLE II.

Decision table for customer demand

X	C_1	C_2	C_3	C_4	C_5	C_6	D
X_1	1	1	1	1	1	1	1
X_2	1	1	1	2	1	1	1
X_3	1	1	1	3	1	1	2
X_4	1	1	2	1	1	1	1
X_5	1	1	2	2	1	1	2
X_6	1	1	2	3	2	1	3
X_7	1	1	3	1	1	1	2
X_8	1	1	3	2	1	1	3
X_9	1	1	3	3	1	2	3
X_{10}	1	2	1	1	1	1	1
X_{11}	1	2	1	2	1	1	1
X_{12}	1	2	1	3	2	1	3
X_{13}	1	2	2	1	2	1	2
X_{14}	1	2	2	2	1	1	2
X_{15}	1	2	2	3	2	1	3
X_{16}	1	2	3	1	2	1	3
X_{17}	1	2	3	2	3	1	3
X_{18}	1	2	3	3	2	1	3
X_{19}	2	1	1	1	1	1	1
X_{20}	2	1	1	2	1	1	2
X_{21}	2	1	1	3	1	1	3
X_{22}	2	1	2	1	1	1	1
X_{23}	2	1	2	2	1	1	1
X_{24}	2	1	2	3	2	1	3
X_{25}	2	1	3	1	2	2	3
X_{26}	2	1	3	2	1	1	3
X_{27}	2	1	3	3	2	1	2
X_{28}	2	2	1	1	1	1	1
X_{29}	2	2	1	2	1	1	2
X_{30}	2	2	1	3	2	1	3
X_{31}	2	2	2	1	1	1	2
X_{32}	2	2	2	2	1	2	2
X_{33}	2	2	2	3	2	1	3
X_{34}	2	2	3	1	2	1	3
X_{35}	2	2	3	2	1	3	3
X_{36}	2	2	3	3	2	1	3
X_{37}	2	2	2	2	1	2	3

C_1, C_2, C_3, C_4, C_5, C_6 are condition attributes, D is decision attribute.

After calculation, $Pos_C(D) = \{ X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}, X_{18}, X_{19}, X_{20}, X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{26}, X_{27}, X_{28}, X_{29}, X_{30}, X_{31}, X_{33}, X_{34}, X_{35}, X_{36} \}$;

$Pos_{C-\{C_1\}}(D) = \{\{X_1, X_{19}\}, \{X_4, X_{22}\}, \{X_6, X_{24}\}, \{X_8, X_{26}\}, \{X_{10}, X_{28}\}, \{X_{12}, X_{30}\}, \{X_{15}, X_{33}\}, \{X_{16}, X_{34}\}, \{X_{18}, X_{36}\}, \{X_7\}, \{X_9\}, \{X_{13}\}, \{X_{14}\}, \{X_{17}\}, \{X_{25}\}, \{X_{27}\}, \{X_{31}\}, \{X_{35}\}\}$

Because $Pos_C(D) \neq Pos_{C-\{C_1\}}(D)$, C_1 is irreducible to decision attribute. In a similar way, C_2, C_3, C_4 are irreducible. As with C_5 and C_6, $Pos_C(D) = Pos_{C-\{C_5\}}(D)$, $Pos_C(D) = Pos_{C-\{C_6\}}(D)$, C_5 and C_6 are reducible.

$\gamma_C(D) = card(Pos_C(D)) / card(X) = 0.946$;

$\gamma_{C-\{C_1\}}(D) = card(Pos_{C-\{C_1\}}(D)) / card(X) = 0.730$;

$\beta(C_1) = \gamma_C(D) - \gamma_{C-\{C_1\}}(D) = 0.216$; $\beta(C_2) = 0.108$;

$\beta(C_3) = 0.460$; $\beta(C_4) = 0.378$; $\beta(C_5) = 0$; $\beta(C_6) = 0$

Objective weight: $g(C_1) = 0.186$; $g(C_2) = 0.093$; $g(C_3) = 0.396$; $g(C_4) = 0.325$; $g(C_5) = 0$; $g(C_6) = 0$.

Procedure 3: subjective weight: $\lambda(C_1) = 0.2$; $\lambda(C_2) = 0.12$; $\lambda(C_3) = 0.25$; $\lambda(C_4) = 0.25$; $\lambda(C_5) = 0.08$; $\lambda(C_6) = 0.1$. Choose experience factor $\zeta = 0.8$.

Procedure 4: according to investigation and data, a DEA model including one input and two outputs is constructed. Decision unit should satisfy $n \geq 2(m+s)$, shown as Table III.

TABLE III.

Calculation of Relative Efficiency

DMU	Input data Design and manufacturing capabilities	Output data Plan improvement goal	 Competitiveness assessment	Relative Efficiency θ_i
C_1	7	2	3	0.75
C_2	4	3	4	1
C_3	6	2	3	0.75
C_4	5	2	2	0.667
C_5	3	3	4	1
C_6	1	3	3	1

Procedure 5: according to the equation $B_i = \frac{\theta_i \times [\zeta \times g_i + (1-\zeta) \times \lambda_i]}{\sum_{i=1}^{n} \theta_i \times [\zeta \times g_i + (1-\zeta) \times \lambda_i]} (i = 1, 2, ..., n)$, final importance of each demand are: $B_{C_1} = 0.187$; $B_{C_2} = 0.130$; $B_{C_3} = 0.363$; $B_{C_4} = 0.273$; $B_{C_5} = 0.021$; $B_{C_6} = 0.026$.

V. Conclusion

This paper adopts the combination of Rough Set theory and Data Envelopment Analysis to determine the importance of customer demand in Quality Function Deployment. Firstly, Rough Set theory is employed with the experts' experiences to modify the condition where weight is 0 and reduced, considering its real significance. Fundamental importance of customer demand is determined by combining customers' preferences and experts' experiences. Then, DEA is used to analyze modifying factors, making demand as decision units, conditions like competitiveness difference as input and output indicators. Pure technical relative efficiency is obtained. Avoiding the impact of man-made factors, its results are more likely to accurately reflect the willing of enterprises and customers improving products. At last, final importance of customer demand is confirmed by combing fundamental importance with relative efficiency in QFD. This approach takes comprehensive consideration of factors like customer demand, enterprises' willingness and competitors' pressure, matching the reality. In the process of modifying factors, experts' experiences are introduced to make up the weakness caused by customers' individual preferences, making a new exploration of the special condition where the importance of customer demand is 0. A case study is conducted to verify the effectiveness of this approach. Results show that it is feasible, valid and provides a new method to determine customer demand in House of Quality.

Appendix A List of symbols

C	customer demand	D	customer satisfaction
ζ	experience factor	λ_i	subjective weight
θ_i	Relative Efficiency		
g_i	objective weight of customer demand		
B_i	the final importance of customer demand		

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