A Group Decision-Making Framework with Various Rating Attitudes Using Fuzzy Set Theory to Prioritize Design Requirements in Quality Function Deployment

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A structured method is called quality function deployment (QFD) that translates the voice of the customer into both of the product and service development. The architecture of QFD is composed of a set of matrices that is often referred to as the house of quality (HOQ). HOQ is regarded as a part of the QFD process. The matrices of HOQ include the importance of customer requirements and the relationship between customer requirements and design requirements collected by the decision-making process of a group of people with ambiguousness and fuzziness. Besides, a group of people make decisions to evaluate fuzzy information with different rating or risk-taking attitudes such as optimistic, neutral, and conservative attitudes. Therefore, a group decision-making framework with various rating attitudes using fuzzy set theory can be used in QFD to identify the importance of each design requirement. Furthermore, a numerical example is solved to show that this group decision-making framework with risk-taking attitudes using fuzzy set theory can be accurately and convincingly applied in QFD for prioritizing design requirements with diverse rating attitudes to help the companies increase customer satisfaction and market share.

1. INTRODUCTION

It is essential to obtain input from customers in order to guarantee that what kinds of the product and service they will want. Although collection data can be unofficially analyzed by communications with customers, there is a better way to officially organize customer needs (Stevenson, 2007). Quality function deployment (QFD) is to translate customer requirements into the appropriate design requirements for each stage of product or service development process. It is a technique used to refine existing offerings by some manufacturing and service industries. (Chan and Wu, 2002, 2002-03, 2005; Krajewski et al., 2007). The QFD usually requires four phases. There are product planning (also called the house of quality (HOQ)), parts deployment, process planning, and production planning phases, respectively (Han et al., 2004; Chan and Wu, 2002-03, 2005). The QFD encourages cross-functional communications and develops the useful information from product planning and process design to manufacturing and delivery to identify the processes that are significant to improve the quality of the product or service as perceived by the customers (Hauser and Clausing, 1988; Gryna, 2001; Chan and Wu, 2002-03, 2005; Krajewski et al., 2007).

The HOQ formed by the set of matrices is usually known as the first phase of QFD because it has design-driven features and offers a way to translate feedback from customers into design requirements. Therefore, the HOQ is commonly viewed as a valuable resource for designers of the product and service development, and it is depicted in Figure 1. (Chan and Wu, 2002-03, 2005; Karsak, 2004; Stevenson, 2007). The most significant advantage of HOQ is that it helps the cross-functional team members to work closely together and concentrate on developing a product or service that satisfies customer requirements. (Hauser and Clausing, 1988; Tan and Shen, 2000; Chase et al., 2006). The structure of the HOQ process has six parts shown as follows: (1) customer requirements (WHATs), (2) competitive assessment, (3) design requirements (HOWs), (4) relationship matrix between WHATs and HOWs, (5) correlation matrix, and (6) specifications or target values (Liu and Wu, 2007; Stevenson, 2007). It is necessary for effectively implementing HOQ to determine the importance of each customer need (requirement) and the relationship between customer requirements and design

requirements. Generally, the importance of the customer requirement can be obtained from market surveys, focus groups, interviews, and trade shows, and the relationship between customer requirements and design requirements can be identified by a group of cross-functional team members (Gryna, 2001; Fitzsimmons, 2006).
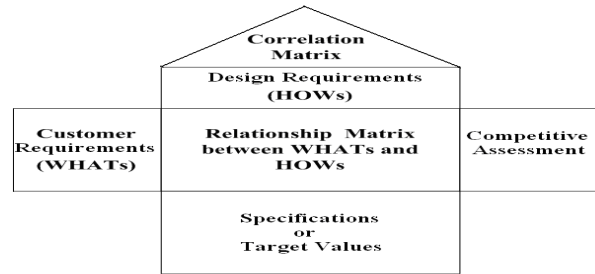

Figure 1. The house of quality

Customers usually have different views because of the various experiences and individual preferences such as optimistic, neutral, and conservative (pessimistic) risk-taking attitudes. The members of a cross-functional team might also have significantly diverse and subjective views to identify the relationship matrix between (WHATs) and (HOWs) according to their past experience and preferences during the decision-making process. Hence, identifying both WHATs and the relationship between (WHATs) and (HOWs) can be regarded as a group decision-making process. There have been some studies on the decision-making process with the fuzzy method issues in QFD. Fung et al. (1999) have presented a fuzzy inference system to analyze the relationship customer requirements and design requirements with fuzziness and identify design targets of product attribute. Karsak (2004) have provided a fuzzy multiple objective programming model to combine vague and subjective information into the decision-making process of the QFD implementation to measure the importance of design requirements. Furthermore, Bottani and Rizzi (2006) have developed a method with fuzzy logic to resolve the qualitative linguistic variables filled with ambiguousness and imprecision in QFD for improving logistics performances, and promoting customer satisfaction and market shares.

Many researchers such as Bahrami (1994), Kalargeros and Gao (1998), Temponi et al. (1999), Vanegas and Labib (2001), and Chan and Wu (2005) have utilized fuzzy methods to analyze and discuss imprecise and often vague issues in the importance of WHATs and the relationship between WHATs and HOWs by applying fuzzy set theory. Nevertheless, these researches never study group decision-making processes with risk-taking attitudes such as optimistic, neutral, and conservative attitudes in QFD by using the information collected from the customers and the cross-functional team members because they could have various preferences in identifying the importance and the relationship during each individual decision-making process. Therefore, we should make use of a group decision-making framework with risk-taking attitudes by using fuzzy set theory applied in QFD to resolve group decision-making processes filled with fuzziness and diverse individual rating attitudes in this study.

This study is organized in the following. In section 1, the background and motive of this research are introduced. The main concepts of the operations of trapezoid fuzzy numbers and the ranking method of fuzzy suitability indices are reviewed in section 2. A proposed model is provided in section 3. A numerical example is presented in Section 4 to illustrate how this proposed model really works under a group decision-making with different rating attitudes. Finally, in Section 5, conclusions are drawn.

2. FUZZY OPERATIONS AND RANKING METHOD OF FUZZY SUITABILITY INDICES

In this section, the fundamental concepts of fuzzy operations, particularly the operations of trapezoid fuzzy numbers, and the ranking method of fuzzy suitability indices are simply reviewed.

2.1 Operations of trapezoid fuzzy numbers
The fuzzy set theory was developed by Zadeh (1965), and the definition of the fuzzy numbers was proposed by Jain (1976), and Dubois and Prade (1978). The concept of trapezoid fuzzy numbers in this study is briefly illustrated as follows.

A fuzzy number B in R (real line) is a trapezoid fuzzy number if its membership function $f_B : R \rightarrow [0,1]$ is equal to

$$f_B(x) = \begin{cases} \dfrac{x-c}{a-c}, & c \le x \le a, \\ 1, & a \le x \le b, \\ \dfrac{x-d}{b-d}, & b \le x \le d, \\ 0, & otherwise, \end{cases} \quad \dots (1)$$

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with $c \leq a \leq b \leq d$. The trapezoid fuzzy number can be denoted by $B = (c, a, b, d)$ as shown in Figure 2. If $a=b$, this trapezoid fuzzy number $B = (c, a, a, d) = (c, b, b, d)$ can be regarded as a triangular fuzzy number $B = (c, a, d) = (c, b, d)$.
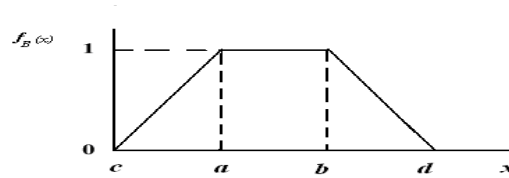

Figure 2. The membership function of a trapezoid fuzzy number $B = (c, a, b, d)$

The fuzzy arithmetic operations of trapezoid fuzzy numbers are provided according to the nature of trapezoid fuzzy numbers and the extension principle (Zadeh, 1965; Liang and Wang, 1993). If two trapezoid fuzzy numbers are $B_i = (c_i, a_i, b_i, d_i)$ and $B_j = (c_j, a_j, b_j, d_j)$, ($B_i > 0$ and $B_j > 0$), then the algebraic calculation of the trapezoid fuzzy numbers are expressed as:

Addition $\oplus$: $B_i \oplus B_j = (c_i + c_j, a_i + a_j, b_i + b_j, d_i + d_j)$, $(i, j \in N)$;…(2)

Multiplication $\otimes$: $h \otimes (c, a, b, d) = (hc, ha, hb, hd)$,

$$B_i \otimes B_j \cong (c_i c_j, a_i a_j, b_i b_j, d_i d_j), \ (d_i d_j \geq 0); …(3)$$

2.2 The Ranking Method of Fuzzy Suitability Indices

Many fuzzy ranking methods for fuzzy numbers have been developed (Chen, 1985; Kim and Park, 1990; Liang and Wang, 1993; Fortemps and Roubens, 1996; Wang and Kerre, 2001). The ranking method with the maximizing set and the minimizing set is applied to rank fuzzy suitability indices (fuzzy numbers) for simply and effectively dealing with problems (Chen, 1985; Kim and Park, 1990; Liang and Wang, 1993; Wang and Kerre, 2001). The ranking method with the maximizing set and the minimizing set is briefly reviewed in the following.

Assume $C_{it} = (g_{it}, h_{it}, i_{it})$ and $W_t = (b_t, c_t, d_t)$, i=1, 2,…, m; t=1, 2,…, q, are triangular fuzzy numbers. C_{it} and W_t can be aggregated as $H_i = (\frac{1}{q}) \otimes [(C_{i1} \otimes W_1) \oplus (C_{i2} \otimes W_2) \oplus … \oplus (C_{iq} \otimes W_q)]$ through averaging the products between the criteria ratings and the relative weights (Kaufmann and Gupta, 1985). Let H_i (i=1, 2,…, m) be the fuzzy suitability indices (fuzzy numbers) of the m alternatives. By the extension principle, a fuzzy suitability index H_i with the membership function is expressed as Equation (4) (Kaufmann and Gupta, 1985; Liang and Wang, 1993; Wang and Kerre, 2001).

$$f_{H_i}(x) = \begin{cases} -R_{i1} + \sqrt{R_{i1}^2 + \dfrac{x - Q_i}{S_{i1}}}, & Q_i \leq x \leq X_i, \\ R_{i2} - \sqrt{R_{i2}^2 + \dfrac{x - Y_i}{V_{i1}}}, & X_i \leq x \leq Y_i, \\ 0, & otherwise \end{cases} \quad \text{for } i=1, 2,…, m,…(4)$$

where
$$S_{i1} = \frac{\sum\limits_{t=1}^{q} (h_{it} - g_{it})(c_t - b_t)}{q}, \quad S_{i2} = \frac{\sum\limits_{t=1}^{q} b_t(h_{it} - g_{it}) + g_{it}(c_t - b_t)}{q}, \quad V_{i1} = \frac{\sum\limits_{t=1}^{q} (i_{it} - h_{it})(d_t - c_t)}{q},$$

$$V_{i2} = \frac{\sum\limits_{t=1}^{q} d_t(i_{it} - h_{it}) + i_{it}(d_t - c_t)}{q}, \quad R_{i1} = \frac{S_{i2}}{2S_{i1}}, \quad R_{i2} = \frac{V_{i2}}{2V_{i1}}, \quad Q_i = \frac{\sum\limits_{t=1}^{q} g_{it}b_t}{q}, \quad X_i = \frac{\sum\limits_{t=1}^{q} h_{it}c_t}{q}, \quad Y_i = \frac{\sum\limits_{t=1}^{q} i_{it}d_t}{q}.$$

The membership function of the maximizing set Max= $\{(x, f_{Max}(x) \mid x \in R\}$ is defined as:

$$f_{Max}(x) = \begin{cases} \dfrac{x - x_1}{x_2 - x_1}, & x_1 \leq x \leq x_2, \\ 0, & otherwise, \end{cases}$$

and the membership function of the minimizing set Min= $\{(x, f_{Min}(x) \mid x \in R\}$ is defined as:

$$f_{Min}(x) = \begin{cases} \dfrac{x - x_2}{x_1 - x_2}, & x_1 \le x \le x_2, \\ 0, & otherwise, \end{cases}$$

where $x_1 = \inf F,\ x_2 = \sup F,\ F = \bigcup_{i=1}^{m} H_i,\ H_i = \{x \mid f_{H_i}(x) > 0\},\ i{=}1, 2,\ldots, m.$

The optimistic utility $U_O(H_i)$ and the pessimistic utility $U_P(H_i)$ of each fuzzy suitability index H_i are defined as follows (Liang and Wang, 1993; Wang and Kerre, 2001):

$$U_O(H_i) = \sup_x (f_{H_i}(x) \wedge f_{Max}(x)),\ \text{for } i{=}1, 2,\ldots, m,\ldots(5)$$

and $\qquad U_P(H_i) = 1 - \sup_x (f_{H_i}(x) \wedge f_{Min}(x)),\ \text{for } i{=}1, 2,\ldots, m.\ldots(6)$

Define the ranking value $U_R(H_i)$ of the fuzzy suitability indices as follows (Liang and Wang, 1993; Wang and Kerre, 2001):

$$U_R(H_i) = \beta U_O(H_i) + (1 - \beta)U_P(H_i),\ \text{for} \qquad i{=}1, \qquad 2,\ldots, \qquad m; \qquad 0 \le \beta \le 1.\ldots(7)$$

where $H_i = (Q_i, X_i, Y_i; R_{i1}, S_{i1}; R_{i2}, V_{i1})$, and the membership function of the fuzzy suitability index H_i shown as equation (4).

The index value of the rating attitude β can reflect the decision-maker's risk-taking attitude. When $\beta > 0.5$, it means that the decision-maker is a risk-lover (optimism). When $\beta = 0.5$, it means that the decision-maker is neutral. Furthermore, when $\beta < 0.5$, it means that the decision-maker is a risk-averter (pessimism). The ranking values $U_R(H_i)$ of the fuzzy suitability index H_i can be obtained by equation (4)-(7):

$$U_R(H_i) = \beta\left[R_{i2} - \sqrt{R_{i2}^2 + \frac{x_U - Y_i}{V_{i1}}}\right] + (1 - \beta)\left[1 + R_{i1} - \sqrt{R_{i1}^2 + \frac{x_L - Q_i}{S_{i1}}}\right]\ \text{for } 0 \le \beta \le 1, \ldots(8)$$

where $x_U = \dfrac{\left\{2x_1 + 2R_{i2}(x_2 - x_1) + \frac{(x_2 - x_1)^2}{V_{i1}} - (x_2 - x_1)\sqrt{(2R_{i2} + \frac{x_2 - x_1}{V_{i1}})^2 + \frac{4(x_1 - Y_i)}{V_{i1}}}\right\}}{2}$, and $x_L = \dfrac{\left\{2x_2 + 2R_{i1}(x_2 - x_1) + \frac{(x_2 - x_1)^2}{S_{i1}} - (x_2 - x_1)\sqrt{(2R_{i1} + \frac{x_2 - x_1}{S_{i1}})^2 + \frac{4(x_2 - Q_i)}{S_{i1}}}\right\}}{2}$

3. AN ALGORITHM OF THE GROUP DECISION-MAKING FRAMEWORK WITH RISK-TAKING ATTITUDES USING FUZZY SET THEORY IN QFD

A stepwise-depicted algorithm of the group decision-making model with risk-taking attitudes using fuzzy set theory based on the ranking method of fuzzy suitability indices (Chen, 1985; Kim and Park, 1990; Liang and Wang, 1993; Wang and Kerre, 2001) applied in QFD is proposed simply in the following:

Step 1: Define the linguistic values as trapezoid fuzzy numbers.

The membership functions of the linguistic values used to assess the importance of each customer requirement (CR) are expressed as follows:

VL (Very low): $(0, 0, 0.1, 0.2)$, $f_w(x) = \begin{cases} 1, & 0 \le x \le 0.1, \\ 2 - 10x, & 0.1 \le x \le 0.2. \end{cases}$

L (Low): $(0, 0.3, 0.3, 0.4)$, $f_w(x) = \begin{cases} \dfrac{10}{3}x, & 0 \le x \le 0.3, \\ 4 - 10x, & 0.3 \le x \le 0.4. \end{cases}$

M (Middle): (0.2, 0.4, 0.6, 0.8), $f_w(x) = \begin{cases} 5x - 1, & 0.2 \le x \le 0.4, \\ 1, & 0.4 \le x \le 0.6, \\ 4 - 5x, & 0.6 \le x \le 0.8. \end{cases}$

H (High): (0.6, 0.7, 0.7, 1), $f_w(x) = \begin{cases} 10x - 6, & 0.6 \le x \le 0.7, \\ \dfrac{10 - 10x}{3}, & 0.7 \le x \le 1. \end{cases}$

VH (Very high): (0.8, 0.9, 1, 1), $f_w(x) = \begin{cases} 10x - 8, & 0.8 \le x \le 0.9, \\ 1, & 0.9 \le x \le 1. \end{cases}$

The membership functions of the linguistic values used to assess the relationship between customer requirements (CR) and design requirements (DR) are expressed as follows:

VW (Very weak): (0, 0, 0.1, 0.3), $f_r(x) = \begin{cases} 1, & 0 \le x \le 0.1, \\ \dfrac{3}{2} - 5x, & 0.1 \le x \le 0.3. \end{cases}$

W (Weak): (0, 0.2, 0.2, 0.4), $f_r(x) = \begin{cases} 5x, & 0 \le x \le 0.2, \\ 2 - 5x, & 0.2 \le x \le 0.4. \end{cases}$

M (Medium): (0.3, 0.4, 0.6, 0.7), $f_r(x) = \begin{cases} 10x - 3, & 0.3 \le x \le 0.4, \\ 1, & 0.4 \le x \le 0.6, \\ 7 - 10x, & 0.6 \le x \le 0.7. \end{cases}$

S (Strong): (0.6, 0.8, 0.8, 1), $f_r(x) = \begin{cases} 5x - 3, & 0.6 \le x \le 0.8, \\ 5 - 5x, & 0.8 \le x \le 1. \end{cases}$

VS (Very strong): (0.7, 0.9, 1, 1), $f_r(x) = \begin{cases} 5x - \dfrac{7}{2}, & 0.7 \le x \le 0.9, \\ 1, & 0.9 \le x \le 1. \end{cases}$

Step 2: Aggregate fuzzy importance through all customers by extended addition and scalar multiplication to form comprehensive weight vector W, in which importance $w_j = (1/n) \otimes (w_{j1} \oplus w_{j2} \oplus,...,\oplus w_{jn})$, where $j=1, 2,\ldots, s$, is a trapezoid fuzzy number of the form, n is the number of the customers (Li, 1999),

$$(w_{1j}, w_{2j}, w_{3j}, w_{4j}) = (\frac{1}{n}\sum_{k=1}^{n} w_{1jk}, \frac{1}{n}\sum_{k=1}^{n} w_{2jk}, \frac{1}{n}\sum_{k=1}^{n} w_{3jk}, \frac{1}{n}\sum_{k=1}^{n} w_{4jk}). \quad \cdots (9)$$

Step 3: Aggregate fuzzy relationship ratings through a cross-functional team by extended addition and scalar multiplication to form a comprehensive relationship matrix P, in which relationship rating $p_{ij} = (1/u) \otimes (p^1_{ij} \oplus p^2_{ij} \oplus,...,\oplus p^u_{ij})$, where $i=1, 2,\ldots, m$; $j=1, 2,\ldots, s$, is a trapezoid fuzzy number of the form, u is the number of cross-functional team members (Li, 1999),

$$(p_{1ij}, p_{2ij}, p_{3ij}, p_{4ij}) = (\frac{1}{u}\sum_{r=1}^{u} p\,{}^{r}{}_{1ij}, \frac{1}{u}\sum_{r=1}^{u} p\,{}^{r}{}_{2ij}, \frac{1}{u}\sum_{r=1}^{u} p\,{}^{r}{}_{3ij}, \frac{1}{u}\sum_{r=1}^{u} p\,{}^{r}{}_{4ij}). \cdots (10)$$

Step 4: Aggregate fuzzy relationship ratings with fuzzy importance by extended addition and multiplication to form an importance weighted, comprehensive decision matrix H, in which $h_i = (\frac{1}{s}) \otimes [(p_{i1} \otimes w_1) \oplus (p_{i2} \otimes w_2) \oplus ... \oplus (p_{is} \otimes w_s)]$ is a fuzzy suitability index (fuzzy number) with parabolic membership functions. By the extension principle (Kaufmann and Gupta, 1985), the membership function $f_{h_i}(x)$ of each design requirement (DR_i) can be obtained. $f_{h_i}(x)$ and fuzzy suitability index (fuzzy number) h_i of DR_i are shown as follows,

$$f_{h_i}(x) = \begin{cases} \dfrac{-\pi_i + \sqrt{\pi_i^2 - 4\omega_{1i}(\theta_{3i} - x)}}{2}, & \theta_{3i} \le x \le \delta_{3i}, \\ 1, & \delta_{3i} \le x \le \eta_{3i}, \\ \dfrac{\varepsilon_i - \sqrt{\varepsilon_i^2 - 4\omega_{2i}(\Phi_{3i} - x)}}{2}, & \eta_{3i} \le x \le \Phi_{3i}, \\ 0, & otherwise, \end{cases}$$

$$h_i = (\theta_{3i}, \delta_{3i}, \eta_{3i}, \Phi_{3i}), \text{ for } i = 1,2,3,\ldots,m, \ldots (11)$$

where $\theta_{1i} = \dfrac{\sum_{j=1}^{s}(w_{2j} - w_{1j})(p_{2ij} - p_{1ij})}{s}$, $\theta_{2i} = \dfrac{\sum_{j=1}^{s}[w_{1j}(p_{2ij} - p_{1ij}) + p_{1ij}(w_{2j} - w_{1j})]}{s}$, $\theta_{3i} = \dfrac{\sum_{j=1}^{s} w_{1j}p_{1ij}}{s}$, $\Phi_{1i} = \dfrac{\sum_{j=1}^{s}(w_{4j} - w_{3j})(p_{4ij} - p_{3ij})}{s}$,

$\Phi_{2i} = \dfrac{\sum_{j=1}^{s} w_{4j}(p_{4ij} - p_{3ij}) + p_{4ij}(w_{4j} - w_{3j})}{s}$, $\Phi_{3i} = \dfrac{\sum_{j=1}^{s} w_{4j}p_{4ij}}{s}$, $\delta_{3i} = \dfrac{\sum_{j=1}^{s} w_{2j}p_{2ij}}{s}$, $\eta_{3i} = \dfrac{\sum_{j=1}^{s} w_{3j}p_{3ij}}{s}$, $\pi_i = \dfrac{\theta_{2i}}{\theta_{1i}}$,

$\varepsilon_i = \dfrac{\Phi_{2i}}{\Phi_{1i}}$, $\omega_{1i} = \dfrac{1}{\theta_{1i}}$, and $\omega_{2i} = \dfrac{1}{\Phi_{1i}}$.

Step 5: Define the index value of the risk-taking attitude for an individual decision-maker as the values of σ_k and τ_r, where $k=1, 2,\ldots, n$; $r=1, 2,\ldots, u$, by Equation (12) and (13). The index value of the risk-taking attitude for a group of decision-makers is defined as the values of β, by Equation (14) obtained from Equation (12) and (13). The index values of the rating attitudes σ_k, τ_r, and β can reflect the decision-maker's risk-taking attitude. When they are greater than 0.5, it means that the decision-maker is a risk-lover (optimism). When they are equal to 0.5, it means that the decision-maker is neutral. Furthermore, when they are less than 0.5, it means that the decision-maker is a risk-averter (pessimism).

$$\sigma_k = \frac{\sum_{j=1}^{s} \dfrac{w_{2jk} - w_{1jk}}{[(w_{2jk} - w_{1jk}) + (w_{4jk} - w_{3jk})]}}{s}, \text{ where } k=1, 2,\ldots, n, \ldots (12)$$

$$\tau_r = \frac{\sum_{i=1}^{m}\sum_{j=1}^{s} \dfrac{p\,{}^{r}{}_{2ij} - p\,{}^{r}{}_{1ij}}{[(p\,{}^{r}{}_{2ij} - p\,{}^{r}{}_{1ij}) + (p\,{}^{r}{}_{4ij} - p\,{}^{r}{}_{3ij})]}}{ms}, \text{ where } r=1, 2,\ldots, u \ldots (13)$$

$$\beta = \frac{\sum_{k=1}^{n} \sigma_k + \sum_{r=1}^{u} \tau_r}{n + u} \ldots (14)$$

Step 6: Calculate the ranking values $U_R(h_i)$ for each design requirement DR_i by the ranking method of the fuzzy suitability indices with the maximizing set and the minimizing set (Liang and Wang, 1993; Wang and Kerre, 2001). That is,

$$U_R(h_i) = \beta[\frac{\varepsilon_i - \sqrt{\varepsilon_i^2 - 4\omega_{2i}(\Phi_{3i} - x_U)}}{2}] + (1 - \beta)[1 + \frac{\pi_i - \sqrt{\pi_i^2 - 4\omega_{1i}(\theta_{3i} - x_L)}}{2}] \dots(15)$$

for $0 \le \beta \le 1$, where $x_U = \frac{\left\{2x_1 + \varepsilon_i(x_2 - x_1) + \omega_{2i}(x_2 - x_1)^2 - (x_2 - x_1)\sqrt{(\varepsilon_i + \omega_{2i}(x_2 - x_1))^2 + 4\omega_{2i}(x_1 - \Phi_{3i})}\right\}}{2}$

, and $x_L = \frac{\left\{2x_2 + \pi_i(x_2 - x_1) + \omega_{1i}(x_2 - x_1)^2 - (x_2 - x_1)\sqrt{(\pi_i + \omega_{1i}(x_2 - x_1))^2 + 4\omega_{1i}(x_2 - \theta_{3i})}\right\}}{2}$

Step 7: Rank the design requirements according to the ranking values and select the design requirement with the maximum ranking value as the most optimal design requirement with group risk-taking attitudes obtained from an individual risk-taking attitude.

4. AN ILLUSTRATED EXAMPLE

Assume QFD has three customer requirements, denoted CR and five design requirements, denoted DR in order to show how this proposed approach works. Assume there are seven customers participating in identifying the importance of each CR, and there are nine members in a cross-functional team to determine the relationship between CR and DR. To apply the algorithm presented in Section 3 by the ranking method of fuzzy suitability indices (Chen, 1985; Kim and Park, 1990; Liang and Wang, 1993; Wang and Kerre, 2001), the illustrations are organized by degrees as follows: In Step 1, the linguistic values of the importance for each CR and the relationship between CR and DR are defined. In this illustrated example, five rating scales and the trapezoid fuzzy numbers with membership functions for CR and the relationship between CR and DR are applied and summarized in Step 1 of the algorithm shown in Section 3, where CR = {VL, L, M, H, VH} and the relationship between CR and DR is {VW, W, M, S, VS}.Besides, membership functions of trapezoid fuzzy numbers in Step 1 of the algorithm shown in Section 3 are depicted in Figures 3 and 4, respectively. The importance of each CR evaluated by requesting seven customers is displayed in Table 1, where the customers have obviously various viewpoints and risk-taking attitudes. On the other hand, the relationship between CR and DR assessed by a cross-functional team with nine members are summarized in Table 2.
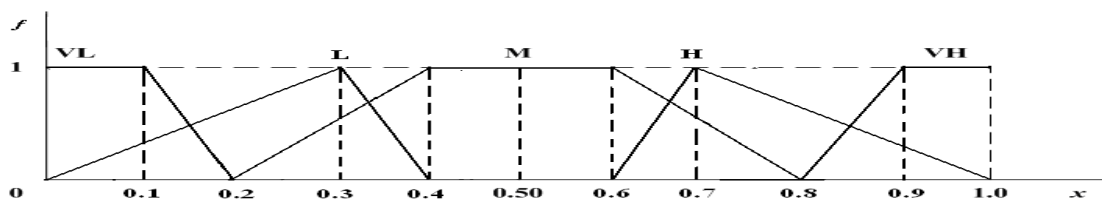
Figure 3. Membership functions of linguistic values {VL, L, M, H, VH} for each CR
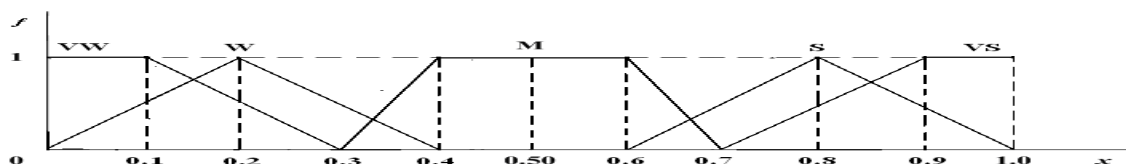
Figure 4. Membership functions of linguistic values {VW, W, M, S, VS} for the relationship between CR and DR.

Table 1. Fuzzy importance evaluated by seven customers for each CR

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7
CR1	L	M	M	VL	H	L	VL
CR2	VH	VH	VH	L	VL	M	L
CR3	L	M	M	M	H	H	VH

Table 2. The relationship between CR and DR evaluated by a cross-functional team

|		DR1	DR2	DR3	DR4	DR5
Member 1		W	VW	M	W	M
Member 2		VW	M	S	VS	S
Member 3		W	W	VW	W	VS
Member 4		S	VS	VS	S	M
Member 5	CR1	VS	S	VS	W	VW
Member 6		M	M	M	VS	S
Member 7		VS	VW	W	VS	M
Member 8		M	M	VS	W	M
Member 9		M	VS	VS	VW	W
Member 1		W	VS	VW	VS	VW
Member 2		VW	S	W	S	VW
Member 3		W	VS	M	S	W
Member 4		M	S	VW	VS	M
Member 5	CR2	S	S	VS	M	S
Member 6		VS	M	VS	M	VS
Member 7		S	M	VW	VW	VS
Member 8		M	VS	VS	M	VS
Member 9		VS	VW	M	W	S
Member 1		VS	VS	S	M	S
Member 2		S	W	VS	M	W
Member 3		S	VS	S	VS	M
Member 4		VS	M	M	M	S
Member 5	CR3	M	M	M	M	VS
Member 6		M	VW	W	W	W
Member 7		VS	VS	VW	VW	VS
Member 8		W	S	M	M	VW
Member 9		W	VS	S	S	VS

In Step 2, aggregate fuzzy importance of these customer requirements (CR) through seven customers by using Equation (9). The aggregated fuzzy importance of each CR is listed in Table 3. Step 3 is to aggregate fuzzy relationship between CR and DR through the cross-functional team members by Equation (10), and the aggregated fuzzy relationship is given in Table 4. In Step 4, a weighted and comprehensive decision matrix (fuzzy suitability index) depicted in Table 5 can be obtained by using extension principle displayed in Equation (11).

Table 3. The aggregated fuzzy importance of each CR

Customer Requirement	Aggregated Fuzzy Importance
CR1	(0.143, 0.3, 0.386, 0.543)
CR2	(0.371, 0.529, 0.614, 0.686)
CR3	(0.371, 0.543, 0.643, 0.829)

Table 4. The aggregated fuzzy relationship between CR and DR

	DR1	DR2	DR3	DR4	DR5
CR1	(0.322,0.467,0.567,0.689)	(0.322,0.444,0.556,0.678)	(0.444,0.6,0.7,0.789)	(0.3,0.478,0.522,0.656)	(0.344,0.478,0.589,0.722)
CR2	(0.356,0.511,0.589,0.722)	(0.5,0.656,0.744,0.856)	(0.3,0.411,0.522,0.633)	(0.389,0.533,0.633,0.756)	(0.4,0.544,0.622,0.744)
CR3	(0.433,0.611,0.689,0.8)	(0.444,0.6,0.7,0.789)	(0.378,0.522,0.611,0.756)	(0.311,0.433,0.567,0.689)	(0.4,0.567,0.633,0.756)

Table 5. The decision matrix (fuzzy suitability index of each design requirement) formed with quadratic membership function by the extension principle

Design Requirement	Fuzzy Suitability Index
DR1	(0.113, 0.247, 0.341, 0.511)
DR2	(0.132, 0.269, 0.374, 0.536)

DR3	(0.105, 0.227, 0.328, 0.496)
DR4	(0.101, 0.22, 0.318, 0.482)
DR5	(0.115, 0.246, 0.339, 0.51)

Step 5 is to calculate σ_k, τ_r, and β, where k=1, 2,…, 7; r=1, 2,…, 9, by Equation (12), (13), and (14). The values of σ_1, σ_2, σ_3, σ_4, σ_5, σ_6, and σ_7, the indices of risk-taking attitudes for seven customers, are 0.833, 0.667, 0.667, 0.417, 0.167, 0.5, and 0.583, respectively. On the other hand, the values of τ_1, τ_2, τ_3, τ_4, τ_5, τ_6, τ_7, τ_8, and τ_9, the indices of risk-taking attitudes for nine members of a cross-functional team, are 0.533, 0.467, 0.6, 0.6, 0.6, 0.6, 0.533, 0.6, and 0.6, respectively. From the results of the above analysis, customer 1, 2, 3, 7, and cross-functional team member 1, 3, 4, 5, 6, 7, 8, 9 are regarded as the risk-lovers (optimism), customer 6 is neutral, but customer 4, 5 and cross-functional team member 2 are regarded as the risk-averters (pessimism). The value of β, an index of a group risk-taking attitude for all the decision-makers including customers and members of a cross-functional team, is 0.56 obtained from aggregating the values of σ_k and τ_r. It represents that a group of the decision-makers are risk-lovers (optimism) when β =0.56>0.5.

Later, Step 6 is to calculate ranking values $U_R(h_i)$ for each design requirement DR_i by Equation (15). The values of $U_R(h_1)$, $U_R(h_2)$, $U_R(h_3)$, $U_R(h_4)$, and $U_R(h_5)$ for these five design requirements are 0.486, 0.531, 0.459, 0.444, and 0.484, respectively. Finally, the importance of these five design requirements can be prioritized according to the ranking values. The design requirement with the maximum ranking value is to be the first priority. Apparently, when β =0.56 (the risk-taking attitudes of all the decision-makers are optimistic), and the ranking order is $DR_2 > DR_1 > DR_5 > DR_3 > DR_4$. That is, to effectively satisfy customer needs, the highest ranking value given to DR_2 suggests that a first-priority objective of an investment in DR_2 might be in order.

The assumed QFD has only three customer requirements, five design requirements, and the analysis of group risk-taking attitudes derived from an individual rating attitude in order to briefly illustrate how this proposed framework works. The contribution of this research is that it can be practically applied in QFD with more customer requirements and design requirements to effectively improve the resolution of a group decision-making process with various rating attitudes.

5. CONCLUSIONS

The basic concept of QFD is to listen to and understand the customer requirements. The architecture of QFD is composed of a set of matrices that is often referred to as the house of quality (HOQ). HOQ is regarded as a part of the QFD process. The matrices of HOQ include the importance of each customer requirement and the relationship between customer requirements and design requirements determined by a group of people with different risk-taking attitudes.

Besides, a group of decision-makers make decisions to assess fuzzy information with diverse rating attitudes such as optimistic, neutral, and conservative attitudes. Therefore, a group decision-making approach with risk-taking attitudes using fuzzy set theory is presented and applied in QFD to resolve group decision-making processes with different rating attitudes. Furthermore, a numerical example is provided to explain how this group decision-making approach with risk-taking attitudes using fuzzy set theory can be accurately and convincingly used in QFD for prioritizing design requirements with various rating attitudes to help the enterprises create higher customer satisfaction and market share.

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BIOGRAPHICAL SKETCH

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