International Journal of Engineering Research and Development
e-ISSN: 2278-067X, **p**-ISSN: 2278-800X, www.ijerd.com
Volume 6, Issue 1 (February 2013), PP. 21-26

A Fuzzy Integrated Methodology for Quality Function Deployment in Manufacturing Industry

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Abstract:- Quality function deployment (QFD) is the product development process to maximize customer satisfaction. The engineering design characteristics related to product performance are specified for this purpose. For dealing with the fuzzy nature in the product design process, fuzzy approaches are applied to represent the relationship between customer requirements (CRs) and engineering design requirements (DRs) as well as among DRs. A new measure for evaluating the fuzzy normalized relationships is derived. A fuzzy approach is formulated to determine the fulfillment level of each DR for maximizing the customer satisfaction under the resource limitation and the considerations of technical difficulty and market competition. This paper is proposing a comprehensive framework in order to formulate strategy in organisations. This research work provides methodology for development of fuzzy based quality function deployment (FBQFD) application in the manufacturing industry. The paper is composed of the background of FBQFD, related research work review and points for developing in manufacturing environment. Then it describes the needs of development of fuzzy based QFD due to uncertainty on the available human experts in product development and expansion resulting in avoiding the lack of the human availability and achieving an expert environment that can predicate the quality of the assuming product with respect of customer demand, so that it can provide system for retrieving design and manufacturing data. In present competitive environment, it is necessary for companies to evaluate design time and efforts at the early stage of product development. However, there is somewhat lacking in systematic analytical methods for product development for product design time (PDT). For this end, this paper explores an intelligent method to evaluate the PDT. At the early development stage, designers are short of sufficient product information and have difficulty in determining PDT by subjective evaluation. Thus, a fuzzy measurable house of quality (FM-HOQ) Approach is proposed to provide measurable engineering information. Quality function deployment (QFD) is combined with a mapping pattern of "function→principle→structure" to extract product characteristics from customer demand.

Keywords: Quality Function Deployment, Fuzzy Logic, Product Design, Quality Control, House of Quality.

I. INTRODUCTION

Quality Function Deployment is an integrative methodology aiming at guiding the process of product development based on customer demands. It works by linking together customer needs, product and parts design requirements, process planning, and manufacturing specifications during product development. Basically, it is based on the use of sequentially connected cross matrix tables in which customer needs are transformed to product characteristics and product and process engineering parameters. QFD stands for **Q**uality **F**unction **D**eployment. Quality Function Deployment is a structured method in which customer requirements are translated into appropriate technical requirements for each stage of product development and production. The QFD process is often referred to as listening to the voice of the customer and is considered a tool of concurrent engineering. Basically, QFD relates the customer requirements (product specifications) to the product design parameters in a mathematical manner. The result of this is a product design driven by math.

The advantages that would be realized through the use of QFD include a reduction in the time required for product design as well as a reduction is those costs associated with the process. This is possible because the design alternatives are realized much earlier in the process thus reducing the number of corrections and design errors. Also, a higher level of clarity for decision making is gained through the use of this tool.

Quality Function Deployment (QFD) is a unique quality tool that allows businesses to plan and design products with the customers' needs in mind. QFD is a structured method for product or service planning. QFD lets a project team specify the customers' needs and then evaluate how the organization is meeting those needs.

By using QFD, a business is motivated to focus on its customers and translate customer requirements into internal product specifications. With good initial requirements the customer obtains a higher quality product in a shorter time.

Fuzzy Concept

Zadeh (1965) introduced the fuzzy set theory to deal with the uncertainty due to imprecision and vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one.
In the classical theory, an element could belong to a set or not. But fuzzy sets and membership developed this concept and introduces raised rate membership. Therefore an element could be a member of a set to a degree. In this theory membership is showed with μ(x) symbol [13]. This value is always between zero and one, as is shown:
$\tilde{A} = \{(x, \mu_A(x) \mid x \in x\}$

The Fuzzy numbers are in many shapes, but triangular and trapezoidal fuzzy number forms are used more. In this study we use the triangular fuzzy numbers. Membership function of triangular fuzzy numbers (a,b,c) are defined as follow:

$$\mu(x) = \begin{cases} \frac{x-a}{b-a} \\ \frac{c-x}{c-b} \\ 0 \end{cases}$$

$\tilde{A} = (a_1, b_1, c_1)$ and $\tilde{B} = (a_2, b_2, c_{21})$ are two triangular fuzzy numbers, Algebraic mathematical operations on them are defined as below:

$$\tilde{A} + \tilde{B} = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \qquad \tilde{A} - \tilde{B} = (a_1 - c_2, b_1 - b_2, c_1 - a_2)$$

$$\tilde{A} \times \tilde{B} = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2) \qquad \frac{\tilde{A}}{\tilde{B}} = \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right)$$

Review on current approaches

Although QFD has been proposed and put in use for several decades, it is still in its developmental stage (Xie, Tan, & Goh, 2003). The structure of the QFD models was strengthen by integrated different traditional techniques and approaches such as Total Quality Management (TQM), Theory of solving inventive problems (TRIZ), Failure Mode and Effects Analysis (FMEA), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and artificial intelligence. (Cristiano, Liker, & White, 2000; Delano, Parnell, Smith, & Vance, 2000; Griffin, 1992; Masui, Sakao, Kobayashi, & Inaba, 2003; Matzler & Hinterhuber, 1998; Price, 1995; Tottie & Lager, 1995; Yamashina, Ito, & Kawada, 2002; Karsak, 2004; Buyukozkan & Feyzioglu, 2005; Chen, Fung, & Tang, 2006; Kahraman, Ertay, & Buyukozkan, 2006; Lin, Wang, Chen, & Chang, 2008). As a critical contribution to the literature, this study presented an integrated model using FAHP and FAD on the basis of QFD framework in order to extend the HoQ principles to investment planning. The extension of HoQ towards shipping investment process which is the so-called Ship of Quality (SoQ) is originally proposed in this paper. The integrated algorithms of SoQ are structured in detail in further sections.

II. METHODOLOGY

QFD is a customer-driven product design tool. Though the proposed method emphasizes a competitive environment, we cannot overlook customers' views. It is important to incorporate the voice of the customer into the importance ratings of the customer requirements. For instance, if the performance of one's own product on one customer requirement is extremely bad, worst of all competitors, we put many efforts to improve it.

A. **Fuzzy Rating Model Development**

1. Product Characteristics (Design Matrix-I)

Step 1: Structuring customer requirements

This step prepares the project. Many activities are involved in this step. The most important goal in this step is to derive the customer requirements structure. Customer requirements can be obtained from several methods, e.g. comment cards, formal surveys, focus group, direct customer contact, field intelligence, complaint analysis, and internet monitoring. The customer requirements structure is usually obtained from affinity or tree diagrams (Evans & Lindsay, 2002). A well-defined customer requirement structure using tree diagram looks as shown in Fig. 2. The customer requirement structure provides the direction for the comparison of competitor products. Other activities, such as deciding the aim of the project, identifying the competitive environment, defining the target customer segment, and so on, are also prepared in this step.

Step 2: Formulating the fuzzy performance-rating matrix

The fuzzy performance-rating matrix presents how well each competitive product performs on each customer requirement. In traditional QFD, the performance-rating matrix is listed at the right side of the House of Quality (HOQ). This indicates where the current market position of one's own product is.

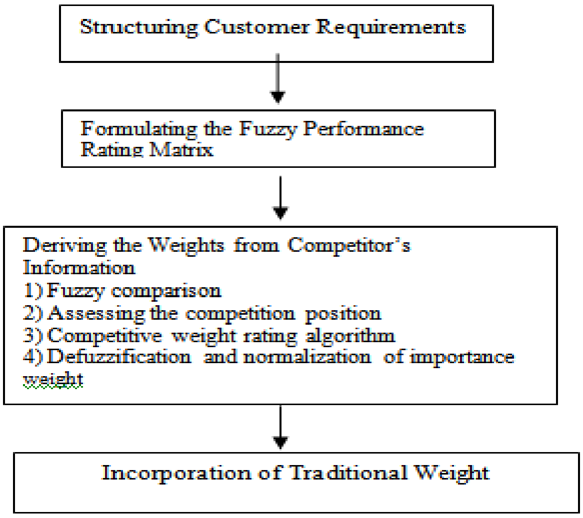

Fig. 1. Conceptual process model

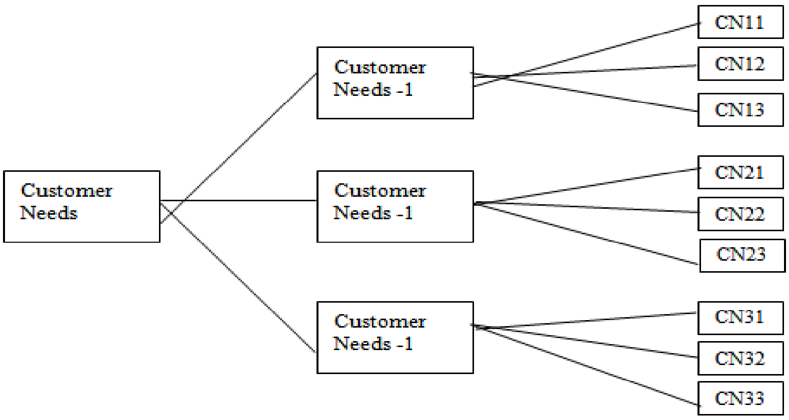

Fig. 2. Customer Needs Structure

Traditional point scales (e.g. 1–3–5, 1–9) are used to evaluate the performance of a product (Hauser & Clausing, 1988, 1996). This matrix is usually obtained from customer surveys. However, this is only an ideal situation. Crisp numbers cannot clearly identify the true performance of a product. In practice, different customers have different attitudes toward the same product. Their rating cannot be the same as each other. What is needed is a suitable tool to capture this information. Fuzzy mathematics is a good tool to capture the highly uncertain information. To present the true rating information, we use the fuzzy performance-rating matrix. Suppose that there are k companies (competitors) and m customer needs denoted by C_k and CN_m, respectively. Here x_{ij} means the jth company's performance on the ith customer requirement.

$$\begin{array}{c} \\ CN_1 \\ CN_2 \\ \vdots \\ \vdots \\ \vdots \\ CN_m \end{array} \begin{bmatrix} C_1 & C_2 & --- & --- & C_k \\ x_{11} & x_{12} & --- & --- & x_{1k} \\ x_{21} & x_{22} & --- & --- & x_{2k} \\ \vdots & \vdots & \ddots & & \vdots \\ \vdots & \vdots & & \ddots & \vdots \\ \vdots & \vdots & & \ddots & \vdots \\ x_{m1} & x_{m2} & --- & --- & x_{mk} \end{bmatrix}$$

Fig. 3. Performance rating Matrix

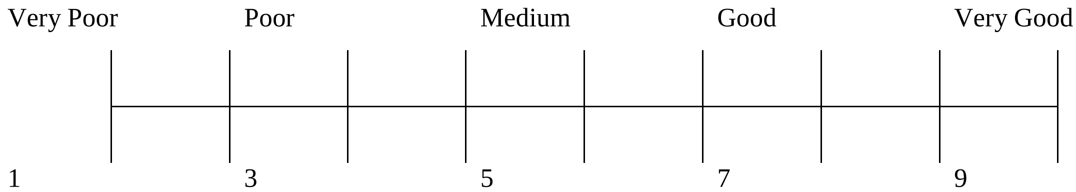

Fig. 4. Point scale Rating

Step 3: Deriving the weight from competitor's information

The aim of this step is to obtain the weight from the analysis of competitive environment. The weight in this step is generated from two aspects: competition and performance. This step contains four minor steps. First, we use the fuzzy performance rating matrix to compare the performance of own product and competitors. Based on the comparison, we assess the competition position by classifying the performance into several ranges. After that, we developed an algorithm to derive the fuzzy weight from competition and performance point of view. Finally, we defuzzify and normalize the weight for the next step.

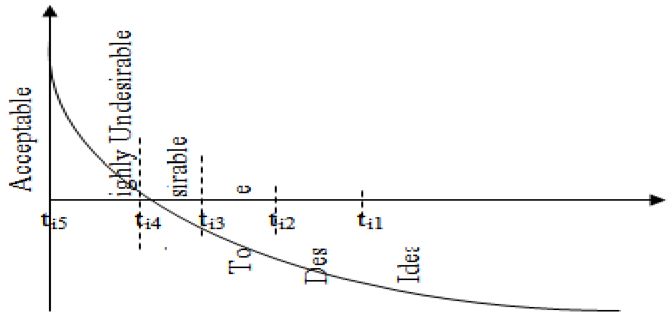

Fig. 5. Competitive position of customer need *i*.

First, the ratings need to be sorted to see the competitive positions of one's own products and of the competitors'. The ratings are fuzzy numbers. Therefore, they need to be defuzzified. Various defuzzification techniques have been proposed, such as the mean-of-maxima (MOM) method, and the fuzzy mean (FM) method (Runkler, 1997; Zhao & Govind, 1991). The MOM method is the easiest one to implement. It selects a non-fuzzy output value corresponding to the maximum value of the membership function. This method results in the most possible solution, but it does not take into account the remaining information given in the fuzzy set. Therefore, the FM method is used. It is defined by:

$$A_D = \frac{\int_X \mu_A(x).x dx}{\int_X \mu_A(x) dx}$$

A_D is the defuzzified value of set A. μ_A (x) is the membership function of A. Unlike the MOM method, the FM method makes a compromise between all possible solutions. Therefore, it can represent the ratings more accurately. After we obtained the crisp ratings, they can be sorted in ascending order.

Step 4: Incorporation of traditional weight

Many previous methods emphasize customer views. In this step we incorporate the weight from customers. The weight can be obtained by many methods. Here we assume that it is known. The compound weight requirement i can be as follows:

$w'_{ic} = rw_{in} + w_{it}$

Where w'_{ic} is the compounded weight, w_{it} is the weight from customer view are r is coefficient. R can be equal, larger, or smaller than 1. After w'_{ic} is obtained, we can normalize is to deduct the final weight w_{ic}.

$$w_{ic} = \frac{w'_{ic}}{\sum_i w'_{ic}} \quad \text{for each i}$$

Then the final weight can be which combines the factors: competition, performance, customer.

2. Production Component Matrix(II)

- The project team breaks down the main and sub components, and places them along the top of Matrix II. It aims to determine the degree of impact that the product design characteristics have on main/sub components.
- Determine relationship values between main/sub components and the product design characteristics.
- The weight of each component is given and normalized similarly as previous. Finally, transferring the components matrix into matrix III. This is manipulated automatically by matlab program with its built-in function.

3. Processes Matrix

This matrix relates the components to its manufacturing processes. The procedures are as follows:

1. The processes are arranged at the top of the matrix. The objective is to determine the interrelationship between the manufacturing processes of the components and the parts components. This helps to identify where emphasis is to be placed on. Soon processes will be related to production and control entities at the last matrix.
2. Quantify the relationship values for each process.
3. The weight of all processes components is automatically calculated by matlab and normalization is done.
4. Transfer the process components and their weights to the next matrix.

4. Production and Control Matrix

➢ Identify the production and control entities with respect to the process components and arrange them at the top of this matrix.
➢ Quantify the relationship values.
➢ Matlab formula calculates the weight of each production and control entities and their normalization values.

At this stage, the corresponding importance of production and control entities is known, so the team can decide on which production and control entities to pay more attention. As a result, it will lead the manufacturing team to concentrate on the right way that significantly reduces the time wasted on guessing. After developing the QFD matrices it is necessary to receive the expertise ideas of giving weights in the relationship among matrices. At that point, the NN is developed based on the QFD matrices structure. The integrated QFD model is shown in figure.

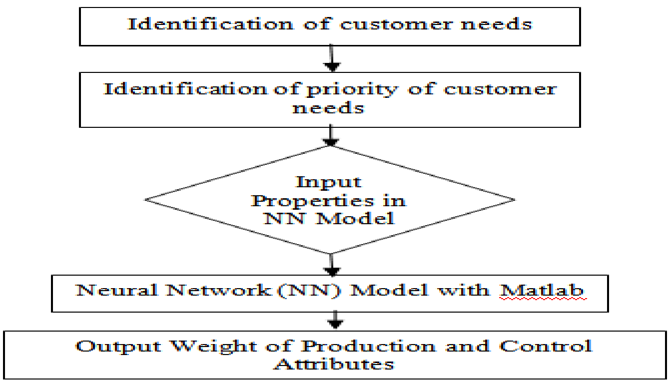

Fig.6. Integrated QFD Model

B. Neural Network (NN) Model

The construction of model is based on the input of customer needs. Among the candidates of network architecture the Multi Layer Perception is chosen for its wide applicability and elementary structure. The NN technique is used to overcome QFD weakness in subjective judgment of relationship values with the help of human expert. Initially, NN needs input of data sets to train the network [4]. The training data sets are generated as follow:

- In the HOQ matrix, the priority for each customer requirements is assigned on a 9-point rating scale.
- The relationship values between customer requirements and product design characteristics are quantified based on the priority of the customer requirements.
- After entering the priority and relationship values into the matrix of HOQ, matlab automatically gives the production and control entities weights in the last matrix's bottom row. This is done by the inter-linking of the matrices in matlab.
- Switching to a different set of priority, the corresponding relationship values yields another set of assembly attribute weights. By repeating the procedures, the training data sets for NN are generated. It is required that each customer requirement priority yields only one set of relationship values.

III. CONCLUSIONS

The proposed method considers competition position, current performance and customer's viewpoint to produce the ratings. In addition, this method uses fuzzy mathematics instead of crisp numbers to capture the true customer requirements. Compared with previous methods, this method is more meaningful and provides companies with a way to find the best product design strategy. Hence the customer requirements are important for the strategy planners in this approach, the relations between the customer's requirements and relations at the top of HOQ are numerically calculated and have impact on internal and external factors of the organisation. Because of uncertainty in the decision making factors the calculations are done in a fuzzy environment.

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