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New product design using FDMS and FANP under fuzzy environment

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ABSTRACT

Quality function deployment (QFD) is a customer-oriented design approach in processing new product developments in order to reach maximum customer satisfaction. Design requirements (DRs) and part characteristics are important decision making problems during QFD activity processes for new product development. Here a Fuzzy decision-making system (FDMS) considering customer needs (CNs) as factors is proposed to formulate the problem. The structure of the FDMS is based on fuzzy control rules. Thus, CNs are determined as input variables and fuzzified using membership function concept. Weights of these factors are then fuzzified to ensure the consistency of the decision maker when assigning the importance of each factor over another. By applying IF–THEN decision rules, DRs of the firm are scored. This paper also uses Fuzzy analytic-network process (FANP) to determine the fulfillment levels of DRs of the firm. The comparison of FDMS with Fuzzy analytical network process (FAHP) is also presented.

1. Introduction

In the global economy, modern organizations face high levels of competition. Global competition prompts business enterprises to actively invest in QFD and to establish a sounder strategic alliance against competitors. QFD attempts to reduce design risk and uncertainty, thus improving customer service and customer satisfaction levels and business processes, and resulting in increased competitiveness, customer satisfaction and profitability. QFD is originated in 1972 in Japan [15]. It has introduced a twofold innovation in traditional product development to improve products quality in Japanese firms. First, the application of QFD requires the careful consideration of customer during the development process [1]. Second, the QFD approach has brought the collaboration among different business areas as a prerequisite for product design. It can easily be adaptable to the area of communication, electronics and electrical utilities, software systems, manufacturing, services, education and research, and many other industries including aerospace, construction, packaging and textile [9]. According to Hauser and Clausing [15], the HoQ (Hause of Quality) is a kind of conceptual map that provides the means for inter functional planning and communications. In today's global and competitive marketplace, the HoQ is a strategic tool to aid companies in developing products that satisfy CNs. There has been some research on quantifying the planning issues in HoQ within the past decade mainly focusing on CNs. Korayem and Iravani [20] improve the robot reliability and quality by applying standard approaches. Armacost et al. [2], Lu et al. [22], Park and Kim [25], Wang [34] employ the AHP (Analytical Hierarchy Process) to prioritize the DRs. Masud and Dean [24], Wasserman [35], Bahrami [3], Khoo and Ho [19], Kalargeros and Gao [17], Bode and Fung [5], Chan et al. [8], Wang [34], Temponi et al. [32], Vanegas and Labib [33], Sohn and Choi [31], Yang et al. [36] employ fuzzy logic to consider the imprecision and vagueness in determining the importance of CNs. The use of ANP in QFD has been used by many researchers. Büyüközkan et al. [7], Kahraman et al. [16], Karsak et al. [18] introduce the network model.

In this study, we propose the use of the FDMS to incorporate the inner dependence issues into CNs and DRs in House of Quality (HoQ). Because of the number, complexity and unclear, vague nature of the variables of the dynamic systems that may influence the manager's decision, fuzzy set theory can be regarded as one of the most appropriate solutions. In most of the real world problems, people prefer to express their preferences as words such as verbal statements. Fuzzy linguistic models permit the translation of verbal expressions into numerical ones, thereby coping quantitatively with imprecision in the expression of the importance of each strategic goal and enabling technology involved in implementing HoQ systems. In this respect, we propose an FDMS algorithm based on FC (Fuzzy Control) rules for ranking a set of feasible DRs of firms. FDMS incorporates the expert knowledge of a human operator in the design of controlling a process whose input–output relationship is described by collection of fuzzy control rules (e.g., IF–THEN rules) involving linguistic variables rather than a complicated dynamic

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mathematical model [4]. Placing CNs variables into fuzzy control inputs and evaluating the system by fuzzy control rules are the focus of this study. By applying FDMS algorithm, firms can easily and efficiently make intelligent choices between DRs. We also apply FANP, which is based on ANP [28] by employing linguistic parameters to emphasize impreciseness and vagueness because of human judgments subjectivity on the importance of DRs related to CNs.

FANP is another method, which can also be used in such quality investment problems in vague issues. FANP involves linguistic variables that describe the quantitative and qualitative factors affecting the quality-based investments. As a result of FANP decision, the relationships between our considerations range from absolutely necessary to undesirable. FANP enables us to take the degree of inner dependences between CNs and DRs into consideration by means of AHP. Partovi [26], Partovi and Corredoira [27], and Karsak et al. [18] use crisp ANP in QFD. There are a number of publications related to FANP applied to QFD in the literature and some of them have been prepared using the multi-attribute/multi-criteria decision-making methods considering human judgments, tangible, intangible and multiple criteria.

In this case study, we apply FDMS and FANP in QFD in a small firm which produces furniture products for child bedroom in furniture sector as a real life application. Like other furnishing organizations, the firm under consideration represents a dynamic and important role of the economy and it desires to improve their products for high quality and services at a reasonable prices. In the beginning of years of 2000s, executive department decided to renovate the firm and its TQM (Total Quality Management) investments. This firm has held all the characteristic of small firm. Managers do not want to spend many resources to implement a complete evaluation of TQM. QFD is therefore used as a powerful tool for improving product design and quality.

This paper is organized as follows: In the next section, we describe QFD, fuzzy numbers, FDMS, FANP fundamentals. Section 3 gives the FDMS and FANP and their applications in QFD in a firm operating in the furniture industry. Concluding remarks are finally presented.

2. Preliminaries

2.1. QFD fundamentals

QFD approach is composed of four successive matrices; such as the customer requirement planning matrix, product characteristics deployment matrix, process and quality control matrix and operative instruction matrix, which are applied to many phases of the product design process [6]. The customer requirements planning matrix, also called the "House of Quality" due to its typical shape, is the first step in investigating customer's needs and requirements. It is composed of two main parts, related to customer's requirements ("what" customer needs) and technical elements ("how" the product has to be made), respectively. The HoQ can be built by following eight step processes. According to Hauser and Clausing [15], those elements are also called "customer's needs" (CNs), and are generally known as a result of surveys or direct questions to customers. CNs are listed in row in the HoQ; if necessary, they can be grouped into sets which express similar expectations (step 1). Customer's attributes are weighted in order to express their relative importance. The weight of each CN is inserted in a column in the matrix (step 2). Next, firms have to establish how their products perform against those of competitors. The results of this step are thus added in a column in the right side of the matrix (step 3). In order to develop a new product, CNs must be translated into "engineering characteristics" (DRs) that probably affect one or more DRs. Engineering characteristics are measurable attributes concerning a

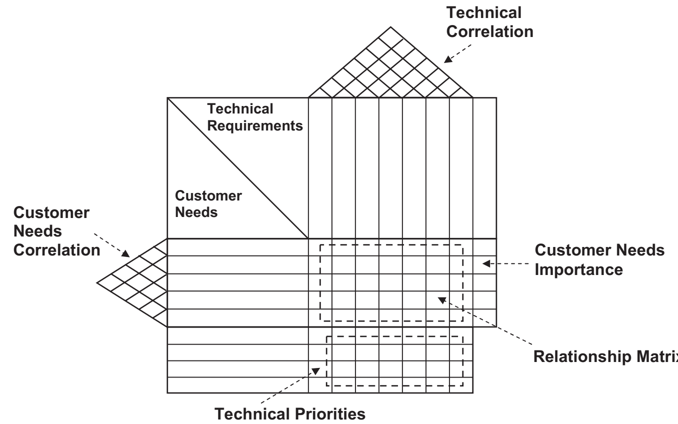

Fig. 1. House of Quality.

firm's product or service; they are listed in columns in the HoQ (step 4). The core element of the matrix is the "relationships matrix". In order to complete this part of the HoQ, the relationships between customer's needs and firm's ability to meet those needs have to be determined (step 5). In a similar manner, the top side of the HoQ, is called the "correlations matrix (step 6). Moreover, firm's products are compared with those of competitors. The work group carries out a quantitative benchmark analysis of competitors' engineering characteristics. The results are added in a row in the lower part of the matrix (step 7). Finally, firms have to introduce a target measure for each DR in the matrix. The target measure translates customer's expectations into numerical values, in order to quantitatively assess firm's performances against customer's requirements. The lower part of the HoQ is therefore completed introducing the goal measure of each DR (Fig. 1) (step 8).

2.2. Fuzzy numbers

Fuzzy set theory introduced by Zadeh [38,39] is suitable for dealing with the uncertainty and imprecision associated with information concerning various parameters. Human judgment is generally characterized by vague language, like 'equally', 'moderately', 'strongly', 'very strongly', 'extremely' and a 'significant degree'. Using such language, decision makers quantify uncertain events and objects. Fuzzy theory enables decision makers to tackle the ambiguities involved in the process of the linguistic assessment of the data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. It provides numerous methods to represent the qualitative judgment of the DM as quantitative data.

Triangular fuzzy numbers are used in this paper to assess the preferences of decision makers. Generally, the fuzzy sets are defined by the membership functions. It represents the grade of any element x of X that have the partial membership to A. The degree to which an element belongs is defined by the value between 0 and 1. If an element x really belongs to A, $\mu_A(x) = 1$ and clearly not, $\mu_A(x) = 0$. The higher is the membership value, $\mu_A(x)$, the greater is the belongingness of an element x to a set A. A triangular fuzzy number is defined as (l, m, u), where $l \leq m \leq u$. The parameters l, m and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. (l, m, u) has the following triangular type membership function.

$$\mu_{A_2}(x) = \begin{cases} \dfrac{x-l}{m-l} & \text{if} \quad l \leq x \leq m, \\ \dfrac{x-u}{m-u} & \text{if} \quad m \leq x \leq u, \\ 0, & \text{otherwise} \end{cases} \tag{1}$$