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The extension of fuzzy QFD: From product planning to part deployment

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ABSTRACT

By focusing on listening to the customers, quality function deployment (QFD) has been a successful analysis tool in product design and development. To solve the uncertainty or imprecision in QFD, numerous researchers have attempted to apply the fuzzy set theory to QFD and have developed various fuzzy QFD approaches. Their models usually concentrate on product planning, the first phase of QFD. The subsequent phases (part deployment, process planning, and production planning) of QFD are seldom addressed. Moreover, their models often use algebraic operations of fuzzy numbers to calculate the fuzzy sets in QFD. Biased results are easily produced after several multiplicative or divisional operations. Aiming to solve these two issues, the objective of this study is to develop an extended fuzzy quality function deployment approach (E-QFD) which expands the research scope, from product planning to part deployment. In product planning, a more advanced method for collecting customer requirements is developed while the competitive analysis is also considered. In part deployment, the original part deployment table is enhanced by including the importance of part characteristics (PCs) and the bottleneck level of PCs. A modified fuzzy *k*-means clustering method is proposed to classify various bottleneck (or importance) groups of PCs. The failure mode and effects analysis (FMEA) is conducted for the high bottleneck (or high importance) group of PCs through the fuzzy inference approach. Moreover, E-QFD employs a more precise method, α-cut operations, to calculate the fuzzy sets in QFD instead of algebraic operations of fuzzy numbers. Finally, a case study is given to explain the analysis process of the proposed method.

1. Introduction

The globalization of market economics has shortened the life cycles of products and has stimulated technological innovation. Reacting to diversifying and fast-changing customer needs is a significant challenge to a company. New product development, which should meet various customer demands, is crucial, not only for the success of the product, but also for the company's survival. Hence, analyzing customer requirements (the voice of customers) and responding to their needs has now become an important and inevitable task for a company's product development team.

By focusing on listening to the customers, quality function deployment (QFD), introduced by Akao (1972), has been a successful tool to help a company's product development team (hereinafter referred to as "the team") systematically translate customer requirements (CRs) to appropriate product features. Generally, a QFD system consists of four inter-linked phases: product planning, part deployment, process planning, and production planning. The output of one phase is employed in the next phase as an input. QFD has been used successfully by industries in both Japan and US (Akao, 1990; Hauser & Clausing, 1988). The success of QFD applications may be the result of some of its benefits, such as high customer satisfaction, greater customer focus, shorter lead time, development of cross-functional teamwork, and preservation of knowledge (Bossert, 1991; Eureka, 1987).

Traditional QFD approaches usually depend on market surveys and customer questionnaires in collecting the importance of customer requirements (CRs). Moreover, in QFD, product developers usually use linguistic terms, such as "a little important", "not too important", or "somewhat important", to assess various input parameters. Nevertheless, the result of the market surveys, customer questionnaires or linguistic terms used is often uncertain, imprecise or ambiguous, resulting in biased analyzed results. To solve this problem, a number of researchers have applied the fuzzy set theory to QFD and have developed various fuzzy QFD approaches. Khoo and Ho (1996) proposed the concept of fuzzy QFD and fuzzified linguistic variables to make them more reasonable. Chan, Kao, Ng, and Wu (1999) applied both fuzzy number and entropy methods to derive the importance of CRs. Wang (1999) developed a new fuzzy outranking method to obtain the importance ranking of engineering characteristics (ECs). Shen, Min, and Tan (2001) added a future tendency index to the importance of CRs when computing for their importance. Shen, Tan, and Xie (2001) focused on ranking the importance of ECs in QFD, and found

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that defuzzification methods have a relatively large impact on its ranking result. Sohn and Choi (2001) applied fuzzy QFD to the supply chain and developed a fuzzy MCDM method to select a design with an optimal combination of reliability and customer satisfaction. Vanegas and Labib (2001) proposed a fuzzy analytical hierarchy process (AHP) method to derive the importance of CRs, and further incorporated important production factors to obtain the importance of ECs. Lin (2003) considered the difficulty involved in the design of ECs and added this factor when computing for the importance of ECs. Tsai (2003) applied the fuzzy integral to rank the importance of ECs, along with an index of decision-makers' forecast of the market. Yang, Wang, Dulaimi, and Low (2003) developed a fuzzy QFD system to support a buildable decision-making design based on the arithmetic operations of fuzzy numbers. Based on the framework of QFD, Büyüközkan, Feyziohlu, and Ruan (2004) developed a fuzzy analytical network process (ANP) method for computing the importance of ECs. Chen, Fung, and Tang (2005) proposed an integrated fuzzy expected value approach to calculate the importance of ECs. Bevilacqua, Ciarapica, and Giacchetta (2006) proposed a decision model for supplier selection based on the QFD. Their approach used the importance of evaluation attributes to rank suppliers. Bottani and Rizzi (2006) translated linguistic values of customer requirements into fuzzy numbers and computed the importance of ECs using the conventional QFD method. Chen, Fung, and Tang (2006) integrated both fuzzy weighted average and fuzzy expected value methods to evaluate the importance of ECs. Chen and Weng (2006) not only considered customer satisfaction, but also the costs and technical difficulties as main goals in the QFD process. They designed a fuzzy goal programming model to achieve the maximum satisfaction degrees of these three goals. Fung, Chen, and Tang (2006) developed an asymmetric fuzzy regression approach, based on QFD, to estimate functional relationships for product planning. Kahraman, Ertay, and Buyukozkan (2006) extended the fuzzy ANP framework in Büyüközkan et al. (2004) by incorporating resource constraints to form a multi-objective programming problem which derived important ECs. Kwong, Chen, Bai, and Chan (2007) developed a fuzzy expert system approach to derive the aggregated importance of ECs by integrating both their importance and their correlation.

From a review of related literatures, two issues can be further investigated. Firstly, as mentioned earlier, QFD is generally composed of four inter-linked phases: product planning, part deployment, process planning, and production planning. Extant studies usually concentrate on developing various methods to derive the importance of ECs. In other words, they only put the focus on product planning, the first phase of the QFD. The remaining three phases are seldom addressed in these literatures. Nevertheless, the exploration of the next three phases can provide the team with valuable information, such as the identification of critical components, the bottleneck level of components, the design parameters, the operation instructions, the inspection methods, etc. Such information can assist the team to effectively identify critical processes and production factors in product development. Hence, the importance of further investigation for subsequent QFD phases should never be underestimated. Secondly, previous studies usually use fuzzy numbers, mostly triangular and trapezoidal fuzzy numbers, to represent the linguistic terms used for assessing the input parameters in QFD. They usually use the algebraic operations of fuzzy numbers to calculate the fuzzy sets in QFD. Theoretically, after the multiplication or division of fuzzy numbers, the result should be curve-shaped rather than linear (Kaufmann & Gupta, 1985). That is, the computation result will no longer be a triangular (or trapezoidal) fuzzy number, resulting in an error. Through several multiplicative or divisional operations, this error will gradually increase, causing a significant deviation of the result from the correct value. A better approach for obtaining more accurate results will be beneficial for the team in order to make a decision during the product development process.

Aiming to solve these two issues, the objective of this research is to develop an extended fuzzy quality function deployment (E-QFD) approach, which expands the scope of extant QFD studies from the product planning phase to the part deployment phase. Moreover, E-QFD will adopt a better computation method to derive the fuzzy sets in QFD. According to Kaufmann and Gupta (1985), the algebraic operations of α-cuts can offer more accurate results than those of fuzzy numbers. Hence, α-cut operations will be employed to calculate the fuzzy sets in QFD.

The rest of this paper is arranged as follows: Section 2 briefly introduces the concepts of QFD, fuzzy numbers and linguistic variables. Section 3 discusses the concept and the detailed steps of the proposed E-QFD approach. Section 4 uses a case company to illustrate the research method of E-QFD, and the last section concludes the present research.

2. Quality function deployment, fuzzy number, and linguistic variable

2.1. Quality function deployment

QFD, which originated in Japan in 1972, was designed to improve quality in product development. It has been a successful tool in assisting product developers systematically incorporate customer requirements (CRs) into product and process development (Akao, 1990). Specifically, QFD systematically brings customer's needs down to the level of detailed operations. Currently, two main QFD approaches have been popularized: the American Supplier Institute's (ASI) Four-Phase approach, and the GOAL/QPC Matrix of Matrices approach. According to Revelle, Moran, and Cox (1998), the difficulty with using the Matrix of Matrices is that it may become more of a maze of mazes instead. Therefore, the ASI's Four-Phase approach was selected as the framework of this research. As shown in Fig. 1, the Four-Phase approach consists of product planning, part deployment, process planning, and production planning phases.

In essence, the product planning phase translates qualitative customer requirements into measurable engineering characteristics, and identifies important engineering characteristics. The part deployment phase translates the output of the product planning into critical part characteristics and explores the relationship between engineering characteristics and part characteristics. The process planning phase establishes the relationship between part characteristics and manufacturing operations related to a part. Critical process parameters are identified and deployed in operation instructions. The production planning phase translates the manufacturing operations into production standards or work instructions, such as the number of parts to be checked, type of tools to be used, the inspection method to be performed, etc. The four phases of QFD share similar structures and analysis processes. Each phase is composed of its WHATs and HOWs, and each phase focuses on the priority analysis of these items based on the information available.

Among the four phases, product planning forms a matrix that is also called the "House of Quality (HOQ)". HOQ indicates the relationship between customer requirements (what to do) and engineering characteristics (how to do it). It is the engine that drives the entire QFD process, and this is why most QFD researches put their focus on this phase only.

2.2. Fuzzy number

Fuzzy set theory, introduced by Zadeh (1965), was developed for solving problems in which descriptions of activities,