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An evidential reasoning based approach for quality function deployment under uncertainty

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ABSTRACT

Quality function deployment (QFD) is a methodology for translating customer wants (WHATs) into relevant engineering design requirements (HOWs) and often involves a group of cross-functional team members from marketing, design, quality, finance and production and a group of customers. The QFD team is responsible for assessing the relationships between WHATs and HOWs and the interrelationships between HOWs, and the customers are chosen for assessing the relative importance of each customer want. Each member and customer from different backgrounds often demonstrates significantly different behavior from the others and generates different assessment results, complete and incomplete, precise and imprecise, known and unknown, leading to the QFD with great uncertainty. In this paper, we present an evidential reasoning (ER) based methodology for synthesizing various types of assessment information provided by a group of customers and multiple QFD team members. The proposed ER-based QFD methodology can be used to help the QFD team prioritize design requirements with both customer wants and customers' preferences taken into account. It is verified and illustrated with a numerical example.

1. Introduction

Quality function deployment (QFD) is a cross-functional planning methodology commonly used to ensure that customer expectations or requirements, often referred to as the voice of the customer (VoC) or WHATs, are deployed through product planning, part development, process planning and production planning. It is a team-based and disciplined approach to product design, engineering and production and provides in-depth evaluation of a product. An organization that correctly implements QFD can improve engineering knowledge, productivity and quality and reduce costs, product development time and engineering changes (Besterfield, Besterfield-Michna, Besterfield, & Besterfield-Sacre, 2003). QFD has now become a standard practice by most leading organizations and has been successfully implemented world widely. A comprehensive literature review of QFD and its extensive applications is provided by Chan and Wu (2002).

The successful implementation of QFD requires a significant number of subjective judgments from both customers and QFD team members. Customers are selected for assessing the relative importance of customer expectations or requirements (WHATs). The QFD team is set up to identify customer wants, map them into relevant engineering requirements, which are often called the HOWs, meaning how the WHATs are to be met, develop the relationship matrix between WHATs and HOWs and the interrelationship matrix between HOWs, and prioritize the HOWs.

As two of the key issues of QFD, prioritization methods for WHATs and HOWs have been extensively researched and quite a number of approaches have been suggested in the QFD literature. For example, the analytic hierarchy process (AHP), a well-known and commonly used multi-criteria decision making method, and its variants:fuzzy AHP, analytic network process (ANP) and fuzzy ANP have been suggested and widely applied to prioritize customer requirements (Akao, 1990; Armacost, Componation, Mullens, & Swart, 1994; Büyüközkan, Ertay, Kahraman, & Ruan,

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2004; Ertay, Büyüuközkan, Kahraman, & Ruan, 2005; Fung, Popplewell, & Xie, 1998; Hanumaiah, Ravi, & Mukherjee, 2006; Kahraman, Ertay, & Büyüközkan, 2006; Karsak, Sozer, & Alptekin, 2003; Kim, Yoon, & Yun, 2005; Kwong & Bai, 2003; Kwong & Bai, 2002; Lu, Madu, Kuei, & Winokur, 1994; Park & Kim, 1998; Partovi, 2007; Wang, Xie, & Goh, 1998). Fuzzy and entropy method (Chan, Kao, Ng, & Wu, 1999; Chan & Wu, 2005) have also been proposed to rate the importance of customer needs. The weighted sum method (Chen & Weng, 2003; Wasserman, 1993), fuzzy weighted average (FWA) (Chen, Fung, & Tang, 2006; Chen & Weng, 2006; Liu, 2005; Vanegas & Labib, 2001), fuzzy outranking approach (Wang, 1999) and grey model (Wu, 2006) have all been suggested for prioritizing engineering design requirements. Fuzzy logic and fuzzy inference have been extensively applied to assess the importance of WHATs and prioritize HOWs (Bottani & Rizzi, 2006; Chen, Chen, & Lin, 2004; Chen, Fung, & Tang, 2005; Karsak, 2004; Karsak, 2004; Khoo & Ho, 1996; Ramasamy & Selladurai, 2004; Shen, Tan, & Xie, 2001; Temponi, Yen, & Tiao, 1999).

To reduce the heavy burden of customers and QFD team members in making their judgments, Franceschini and Rossetto (2002) develop an interactive algorithm for prioritizing product's technical design characteristics, called IDCR (interactive design characteristic ranking), which allows the QFD team to determine a ranking order for design characteristics without using subjective rating scales and explicitly knowing the relative degree of importance of customer requirements. The IDCR algorithm avoids an inappropriate conversion from qualitative information to a relationship matrix. Han, Kim, and Choi (2004) suggest a linear partial ordering approach for assessing the information in QFD and prioritizing engineering characteristics. The linear partial information is used to extract the weights of customer wants and the relationship values between WHATs and HOWs. Four types of dominance relations that are frequently used in multi-attribute decision making with incomplete information are used to determine the priorities of engineering characteristics when the linear partial orderings of customers and QFD team members are given. The dominance relations between engineering characteristics are established through the solution of a number of linear programming models.

Considering the fact that people contributing to the QFD process may give their preferences in different formats, numerically or linguistically, depending on their backgrounds, Büyüközkan and Feyzioğlu (2005) present a fuzzy logic based group decision making approach with multiple expression formats for QFD with the hope to better capture and analyze the demand of customers, where different expressions are aggregated into one collaborative decision by using fuzzy set theory. Their approach is illustrated with a software development example. Ho, Lai, and Chang (1999) also discuss group behaviors in QFD and present an integrated group decision making approach for aggregating team members' opinions in the case where some members in a team have an agreed criteria set while others prefer individual criteria sets. By using voting and linear programming techniques, their integrated approach consolidates individual preferences into a group consensus and is used for determining the relative importance of customer requirements.

The above literature review clearly shows that quite a lot of efforts have been made to deal with fuzziness in the process of QFD. However, no attempt has been made to address the issue of how to deal with incomplete, imprecise and missing (ignorance) information in QFD, which is essentially inherent and sometimes inevitable in human being's subjective judgments. Fuzzy logic based approaches have been extensively used to model vagueness and ambiguity, but it cannot deal with such uncertainties as incomplete, imprecise and missing information. The purpose of this paper is to develop a rigorous and systematic methodology, on the basis of the ER approach (Wang, Yang, & Xu, 2006b; Wang, Yang, Xu, & Chin, 2006a; Xu, Yang, & Wang, 2006; Yang & Singh, 1994; Yang & Sen, 1994; Yang, 2001; Yang & Xu, 2002; Yang & Xu, 2002; Yang, Wang, Xu, & Chin, 2006), for synthesizing various types of assessment information provided by a group of customers and multiple QFD team members, which is referred to as the evidential reasoning (ER) based QFD methodology, in order to handle various types of possible uncertainties that may occur in the implementation process of QFD. The proposed ER-based QFD methodology can be used to help the QFD team to prioritize design requirements with both customer wants and customers' preferences taken into account. It is capable of modeling various types of uncertainties using a unified belief structure in a pragmatic, rigorous, reliable, systematic, transparent and repeatable way.

The rest of the paper is organized as follows:in Section 2, we develop the ER-based QFD methodology and describe in detail its modeling mechanism and steps. The methodology is then verified and illustrated with a numerical example in Section 3. Comparisons with other QFD methodologies are provided in Section 4. The paper is concluded in Section 5.

2. The methodology

The ER approach developed for multiple attribute decision analysis (MADA) has found an increasing number of applications in recent years (Wang et al., 2006a; Wang et al., 2006b; Xu et al., 2006; Yang & Singh, 1994; Yang & Sen, 1994; Yang, 2001; Yang & Xu, 2002; Yang & Xu, 2002; Yang et al., 2006). In this section, we develop an ER-based QFD methodology to deal with various types of uncertainties in QFD. The methodology allows customers and QFD team members to express their subjective judgments using belief structures developed on the basis of the theory of evidence (Shafer, 1976). It also allows customer wants to be aggregated in a rigorous yet nonlinear rather than linear manner. The methodology is described in detail as follows.

2.1. Modeling subjective judgments using belief structures

QFD begins with the identification of customer requirements and their mapping into relevant engineering design requirements, as shown in Fig. 1, where $\mathrm{CR}_1 \sim \mathrm{CR}_m$ are the m identified customer wants (WHATs), $\mathrm{DR}_1 \sim \mathrm{DR}_n$ are the n relevant engineering design requirements (HOWs), $w_1 \sim w_m$ are the relative weights (also called the degrees of importance) of the customer wants with $\sum_{i=1}^{m} w_i = 1$ and $w_i > 0$ for $i = 1, \ldots, m$, $R = (R_{ij})_{m\times n}$ is the relationship matrix between WHATs and HOWs, and $r = (r_{jk})_{n\times n}$ is the interrelationship matrix (also called correlation matrix) between HOWs, satisfying $r_{jk} \equiv r_{kj}$ for $j, k = 1, \ldots, n$. The figure looks similar to a house and is thus often referred to as the house of quality (HOQ).

2.1.1. Modeling the relative importance of customer wants

The relative importance of the identified customer wants is usually assessed by customers rather than by QFD team members because only customers know what they really want and what are more important or less important to them. Suppose there are L customers selected for assessing the relative importance of the m customer wants, each customer associated with a relative weight $\lambda_l > 0$ ($l = 1, \ldots, L$) with $\sum_{l=1}^{L} \lambda_l = 1$.

To help the customers express their opinions on the relative importance of the customer wants, rating scales can be defined and adopted. Table 1 shows one of the possible rating scale definitions. Other rating scales can also be defined. It is not our purpose to explore which rating scale is the best or more appropriate for a specific situation, which is beyond the scope of this paper. Our purpose is to provide a pragmatic yet simple way to elicit customers' preferences and produce an estimate for the relative importance of the customer wants.