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Decision Support

# A group decision-making approach to uncertain quality function deployment based on fuzzy preference relation and fuzzy majority

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ABSTRACT

Quality function deployment (QFD) is one of the very effective customer-driven quality system tools typically applied to fulfill customer needs or requirements (CRs). It is a crucial step in QFD to derive the prioritization of design requirements (DRs) from CRs for a product. However, effective prioritization of DRs is seriously challenged due to two types of uncertainties: human subjective perception and customer heterogeneity. This paper tries to propose a novel two-stage group decision-making approach to simultaneously address the two types of uncertainties underlying QFD. The first stage is to determine the fuzzy preference relations of different DRs with respect to each customer based on the order-based semantics of linguistic information. The second stage is to determine the prioritization of DRs by synthesizing all customers' fuzzy preference relations into an overall one by fuzzy majority. Two examples, a Chinese restaurant and a flexible manufacturing system, are used to illustrate the proposed approach. The restaurant example is also used to compare with three existing approaches. Implementation results show that the proposed approach can eliminate the burden of quantifying qualitative concepts and model customer heterogeneity and design team's preference. Due to its easiness, our approach can reduce the cognitive burden of QFD planning team and give a practical convenience in QFD planning. Extensions to the proposed approach are also given to address application contexts involving a wider set of HOQ elements.



## 1. Introduction

Nowadays, with short life-cycles and dynamic competition in global markets, the major challenge of any product-oriented firm is how to efficiently design, develop, and manufacture new products that will be preferred more by customers than those offered by competitors (Chen & Ko, 2010). Essentially, a product's success depends largely on how it meets customer needs or requirements (CRs). On one hand, the CRs are obtained through a survey conducted by the marketing department, and the output of this is a list of qualitative customer attributes, such as "easy to use", "resistant" or "durable". On the other hand, the design team has to make the product specifications satisfy what the customers want. The design specifications are based on engineering properties with a quantitative nature, such as "automated guided vehicle", "storage and retrieval system" or "programmable logic controller". In this sense, conflict can arise between marketing and engineering departments, as they speak different languages (Hauser & Clausing, 1988).

Quality function deployment (QFD) is one of the very effective customer-driven quality system tools typically applied to fulfill customer needs and, more importantly, to improve customer satisfaction (Chan & Wu, 2002a,b; Chen & Ko, 2011). The most commonly seen QFD consists of four inter-linked stages: Stage 1 to translate CRs into design requirements (DRs); Stage 2 to translate important DRs into product characteristics; Stage 3 to translate important product characteristics into manufacturing operations; and Stage 4 to translate key manufacturing operations into operations and control. Each stage's important outputs (HOWs), generated from the stage's inputs (WHATs), are converted into the next stage as its inputs (new WHATs), i.e., each stage can be described by a two dimensional matrix of "WHATs" and "HOWs", which is easy and convenient to deal with in practice (Chan & Wu, 2005).

The first stage of QFD, also known as house of quality (HOQ), is of fundamental and strategic importance, since it is in this stage that the CRs (WHATs) for the product are identified and converted into appropriate DRs (HOWs) to fulfil customer satisfaction. In other words, HOQ links the "voice of the customer" to the "voice of the technician", through which the process and production plans can be developed in the other stages of the QFD system, as depicted in Fig. 1. The structures and analyzing methods of the other three QFD stages are essentially the same as the first one (Liu & Wu, 2008). Therefore, instead of the

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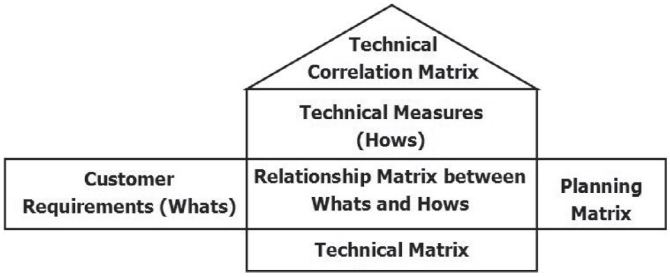


**Fig. 1.** The house of quality.

entire four stages, most QFD studies focus mainly on the first stage to prioritize DRs (HOWs) from CRs (WHATs; e.g., Chen et al., 2006; Ho, Lai & Chang, 1999; Yan, Ma & Li, 2013), which is also the main focus of our current work.

Successful implementation of QFD often requires a significant number of subjective judgments from both customers in a targeted market and a QFD design team in a firm. Such a number of subjective judgments will inevitably generate the following two types of uncertainties for prioritizing DRs in the process of QFD planning.

- The first type of uncertainty is the human assessment and judgment on qualitative attributes, which are always subjective and imprecise. Hence, the input information of human perception can be ambiguous, which presents a special challenge to effective prioritization of DRs (Chen et al., 2006).
- The second type of uncertainty is the involvement of many customers and the QFD design team in the evaluation of input information of QFD. Input information may have an uncertainty associated with customer heterogeneity because each customer may have a different opinion (Kwong et al., 2011; Wang, 2012).

In the past two decades, we have witnessed many studies focusing on these two types of uncertainties in the literature, as reviewed in Section 2.1.

Regarding the first type of uncertainty, it has been found that all existing studies of uncertain QFD have quantified subjective judgments in terms of fuzzy sets (Zadeh, 1965), which is in fact the process of transforming an ordinal scale into a cardinal scale that represents an "arbitrary passage". Such a quantification may sometimes be dangerous (Han, Kim & Choi, 2004), since the fuzzy set based semantics of linguistic labels is often defined subjectively and context-dependently. Consequently, it is easy to generate different results by choosing different scales from which to draw the ordinals. Moreover, even if the quantification process used is rational, existing studies of uncertain QFD perform calculations with the associated fuzzy membership functions of linguistic labels based on fuzzy extension principle (Zadeh, 1965). Such a procedure has, as any fuzzy computation-based approach, an unavoidable limitation of information loss caused by the process of linguistic approximation, which consequently implies a lack of precision in the final result and has been well verified by Herrera and Martínez (2000) in the general context of fuzzy linguistic decision-making. Finally, as observed by Tidd and Bodley (2002), many tools even if available within the firm are not used since they are too complex to be used. Since it is complex and time-consuming to apply QFD in practice (Chan & Wu, 2005), the burden of quantifying qualitative concepts and calculation in terms of fuzzy sets may build an obstacle for the design team to use QFD. With respect to the second type of uncertainty, due to the heterogeneity of customer inputs, it is necessary and important to consider the customer variability so as to derive a robust prioritization of DRs (HOWs; Kwong et al., 2011). As a basic element underlying group decision-making, the concept of *fuzzy majority* is accepted by most of its members in practice, since it is quite difficult for the solution to be accepted by all users (Kacprzyk, Zadrozny, Fedrizzi & Nurmi, 2008). Such a concept of fuzzy majority may represent the design team's preference, which plays an important role in QFD. Therefore, it may provide a better solution to prioritize the DRs by considering the concept of fuzzy majority in uncertain QFD, which is missed in the literature.

Toward this end, the main focus of this paper is to simultaneously cope with the two types of uncertainties underlying QFD by a novel group decision-making approach. Firstly, the proposed approach performs computations solely based on the order-based semantics of linguistic input information. Moreover, it performs the group aggregation of fuzzy preference relations based on the concept of fuzzy majority underlying group decision-making. An exponential Regular Increasing Monotone (RIM) quantifier is used to express the fuzzy majority. Finally, it utilizes the fuzzy majority to derive a consensus degree for the uncertain QFD problem. As we shall see, the proposed approach, on one hand, can eliminate the burden of quantifying qualitative concepts in QFD; on the other hand, it incorporates the fuzzy preference relation and fuzzy majority into uncertain QFD so as to model the customer variability and the design team's attitudinal preference.

The rest of this paper is organized as follows. Section 2 reviews existing approaches to uncertain QFD and formulates our research problem. Section 3 presents how to derive the fuzzy preference relations from users' subjective judgments. Section 4 proposes the group aggregation of individual fuzzy preference relations based on the concept of fuzzy majority. A consensus degree based on fuzzy majority is also given for the uncertain QFD problem. Section 5 examines two examples, a Chinese restaurant and a flexible manufacturing system, to show the effectiveness of the proposed approach. The restaurant example is also used to compare with three existing studies. For the completeness of this study, some considerations and potential ways are discussed in Section 6 to handle other factors in a potentially more comprehensive HOQ model. Finally, the paper is concluded in Section 7 with some remarks.

## 2. Literature review and our QFD framework

### 2.1. Literature review

Several attempts have been made in order to cope with the two types of uncertainties underlying the QFD problem: human subjective perception and customer heterogeneity. To cope with the first type of uncertainty, numerical studies have been conducted on how to prioritize DRs (HOWs) with fuzzy linguistic variables (Zadeh, 1975) semantically represented by fuzzy sets (Zadeh, 1965). For example, Khoo and Ho (1996) developed an approach based on possibility theory and fuzzy arithmetic to address the ambiguity involved in various relationships and outlined the framework of a fuzzy linguistic QFD. Zhou (1998) proposed an approach to prioritize DRs through a fuzzy ranking procedure and to optimize improvements using a mixed integer programming approach, in which the relative importance of CRs were determined by the analytical hierarchy process (AHP) and were assumed to be crisp numbers. Wang (1999) used fuzzy arithmetic to compute the technical importance ratings of DRs and the outranking approach based on possibility and necessity measures to prioritize DRs. Shen, Tan & Xie (2001) employed fuzzy arithmetic to calculate the fuzzy priority weights of DRs and defuzzified them using the mean of maxima method and the centroid defuzzification method. Ertay, Kahraman & Ruan (2005) prioritized DRs by taking into account the degree of interdependence between CRs and DRs, and the inner dependence among them. Liu (2005) devised a method that could prioritize DRs without knowing their exact membership functions by means of fuzzy weighted aggregation (FWA; Liou & Wang, 1992; Kao & Liu, 2001). Chen et al. (2006) calculated the priority weights of DRs using the FWA and fuzzy expected value (FEV) operator (Liu & Liu, 2002). Kwong, Chen, Bai & Chan (2007) developed a new methodology to calculate the importance weights of DRs based on the fuzzy expert systems approach. Chen and Ko (2011) considered the four