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Fuzzy approaches to quality function deployment for new product design

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Abstract

For new product development, quality function deployment (QFD) is a useful approach to maximize customer satisfaction. The determination of the fulfillment levels of design requirements (DRs) and parts characteristics (PCs) in phases 1 and 2 is an important issue during QFD processes for new product design. Unlike the existing literature, which mainly focuses on the DRs, this paper proposes fuzzy nonlinear programming models based on Kano's concept to determine the fulfillment levels of PCs with the aim of achieving the determined contribution levels of DRs in phase 1 for customer satisfaction. In addition, to deal with the design risk, this study incorporates failure modes and effects analysis (FMEA) into QFD processes, and treats it as the constraint factor in the models. To cope with the vague nature of product development processes, fuzzy approaches are used for both FMEA and QFD. The applicability of the proposed models in practice is demonstrated with a numerical example.

Keywords: Design; Fuzzy mathematical programming; Quality function deployment (QFD); Kano's concept; Failure modes and effects analysis (FMEA)

1. Introduction

Quality function deployment (QFD) is a useful customer-driven product development tool for translating the needs of the customer into efficient communication through the various stages of product planning, design, engineering, and manufacturing to achieve higher customer satisfaction. QFD was conceived in Japan in the late 1960s by Akao and then disseminated world-wide [1]. It has been successfully introduced in many industries to improve product design, decision making process, and customer satisfaction [12,16,22]. A typical QFD process consists of four phases. In the new product design stage, a QFD team is organized to implement the first two phases, i.e., product planning and part deployment, of QFD processes, which mirror the product design process to achieve great customer satisfaction. The two phases are closely related at the design stage, since the outcome from the latter phase should make the decisions from the former phase applicable. However, most of the existing literature only focuses on the first phase of QFD, so this study will consider the two phases in QFD activities for a new product design.

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The house of quality (HOQ) is an important tool for QFD activities, containing information on "what", "how", relationship between "what" and "how", and, the relationship between the "how" factors themselves. For example, for the development of phase 1, the QFD team determines a set of "what", i.e., customer requirements (CRs), and "how", i.e., design requirements (DRs), that affect CRs, and then constructs the relation strength between CRs and DRs and the relationships between the DRs themselves. The objective of the first phase is to determine the fulfillment level of DRs to maximize the customer satisfaction. In phase 2, the DRs are considered as "what", and parts characteristics (PCs) are "how" factors designed to maximally achieve the requirement level of DRs. In traditional QFD, the measurements of importance of "what" and the associated relationships are assessed on a scale system such as 1–3–9, or 1–5–9, indicating "weak", "moderate", and "strong", respectively [11,16]. Nevertheless, gathering sufficient knowledge and information about the measurements is usually difficult [9,10]. This has led to the introduction of fuzzy approaches into QFD studies [5,6,9,10,18]. However, these existing studies still suffer from a number of drawbacks in approaches and methodologies, as mentioned by Chen and Weng [9].

In practice, effective design processes can lead to the achievement of maximum customer satisfaction. For instance, in phase 1 of QFD, DRs are able to achieve better effectiveness of the design planning when their performance is highly correlated with CRs to meet external customer satisfaction. The effect of PCs on DRs in phase 2 is comparable to that of DRs on CRs. However, the fulfillment levels of DRs and PCs are not necessarily proportionally consistent with CRs' and DRs' satisfaction, respectively. Kano et al. [17] proposed that quality performance of a product or service has three different relationships (i.e., attractive, one-dimensional, and must-be) with customer satisfaction. Some researchers incorporated Kano's idea into QFD for assigning weights to different "what" to explain how they impact customer satisfaction in different ways [15,25,30–32]. Instead, recently Chen and Ko [8] adopted Kano's concept to categorize DRs in their fuzzy models. Referring to [8], this study applies Kano's concept to classify various "how" into three categories based on their importance ranking, since the performance of various "how" achieves different levels of external/internal customer satisfaction.

Furthermore, in order to decrease risks inherent in of new product design, the risk analysis of DRs is necessary at the design stage of new product development. The outcomes of phase 1, i.e., the fulfillment levels of DRs, are applied to phase 2 as the constraint factors in determining the achievement levels of PCs. With this consideration, failure mode and effect analysis (FMEA) is applied for risk analysis. The influence of DRs' risk levels on PCs in phase 2 is considered in the decision models. FMEA is a systematic technique for identifying, prioritizing and acting on potential failure modes before the failures occur. Several researchers have discussed FMEA and its applications to QFD [2,13,29,30]. However, these studies are only limited to descriptive analyses to obtain the quality and resource benefits. The methods to carry out the aggregation of the QFD and FMEA are not mentioned, and the uncertainty at the new product design stage is not considered, either. In this study, we construct the fuzzy nonlinear mathematical programming models, referring to Kano's concept in phase 1; furthermore, we introduce FMEA into the fuzzy QFD approach, and propose an idea to link the function relationship between phases 1 and 2 of the QFD in determining the achievement levels of "how" in phase 2 to maximize the internal and external customer satisfaction under the relevant constraints. An example of a semiconductor packing case is given to illustrate the proposed models.

In the following section, a fuzzy approach to QFD is introduced. In Section 3, a fuzzy nonlinear model in phase 1 of the QFD process is proposed based on Kano's concept to categorize "how" into three characteristics. In the fourth section, the fuzzy FMEA approach is introduced and a fuzzy nonlinear programming model is developed to determine the achievement degree of PCs, constrained by the need of DRs in phase 1 and the risk rating of PCs according to the development of FMEA on DRs. An example of a semiconductor packing case is presented to demonstrate our approaches in Section 5. Finally, the concluding remarks are provided in Section 6.

2. Fuzzy QFD

The first step in the implementation of QFD processes is usually to construct a relation matrix, called a HOQ, for each phase to define the relationships between "what" and "how". Based on the information contained in the HOQ, the achievement priority or level of output variables can be determined. At the design level, the major work in phase 1 of the QFD processes is to determine the achievement priority or level of "how", i.e., DRs, referring to the importance of each "what", i.e., CR, the relationships between CRs and DRs and the relationships between the DRs themselves. Following the results from the first stage of the QFD process, similar work is performed with DRs and PCs in phase 2.