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Fuzzy linear programming models for new product design using QFD with FMEA

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Abstract

Quality function deployment (QFD) is a customer-driven approach in processing new product developments in order to maximize customer satisfaction. Determining the fulfillment levels of design requirements (DRs) and parts characteristics (PCs) is an important decision problem during QFD activity processes for new product development. Unlike the existing literature, which mainly focuses on the determination of DRs, this paper proposes fuzzy linear programming models to determine the fulfillment levels of PCs under the requirement to achieve the determined contribution levels of DRs for customer satisfaction. In addition, considering the design risk, this paper incorporates failure modes and effect analysis (FMEA) into QFD processes, which is treated as the constraint in the models. To cope with the vague nature of product development processes, fuzzy approaches are used for both FMEA and QFD. The illustration of the proposed models is performed with a numerical example to demonstrate the applicability in practice.
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1. Introduction

Quality function deployment (QFD) is a customer-driven product development tool, considered as a structured management approach for efficiently translating customer needs into design requirements and parts deployment, as well as manufacturing plans and controls in order to achieve higher customer satisfaction. QFD has been successfully introduced in many industries to improve processes, customer satisfaction, and competitive advantages [1,2]. A general QFD process consists of four phases in order to relate the voice of customer to product design requirements (phase 1), and then translate this into parts characteristics (phase 2), manufacturing operations (phase 3), and production requirements (phase 4). In practice, at the design stage of new product development, a QFD team is organized to implement the first and second phases of QFD processes. The two phases are closely related at the design stage, since the outcomes from the latter phase should make the decisions from the former phase applicable. However, most of the existing research only focuses on

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the first phase of QFD in order to maximize customer satisfaction. Thus, the study that considers the two phases in QFD becomes necessary.

For the development at the first phase, the relation matrices between customer requirements (CRs) and design requirements (DRs) and among the DRs are constructed, and the relationships are usually evaluated subjectively by ambiguous or vague judgments, due to the lack of information about the influence of engineering responses on CRs [3,4]. However, those relationships are often treated as crisp variables or linguistic scales [1,2]. For example, the relation strength by which a DR affects a CR is expressed by a scale system, i.e., 1–3–9, or 1–5–9, indicating linguistic expressions such as "weak", "moderate", and "strong", respectively. In order to make the improvements, fuzzy approaches are adopted by several researchers to address diversified and imprecise problems between CRs and DRs and among the DRs [5–10]. However, these existing studies still suffer some drawbacks in approaches, as mentioned by Chen and Weng [3,4] in their fuzzy mathematical programming model for QFD.

Furthermore, in order to decrease the risk of new product design, the risk analysis of DRs is necessary during the design level of new product development, and the outcomes are applied to phase 2 as the constraints in determining the achievement levels of parts characteristics (PCs). In this respect, failure mode and effect analysis (FMEA) is a systematic technique for identifying, prioritizing and acting on potential failure modes before the failures occur, so this study also adopts FMEA for the risk analysis in the early stages of new product development. Stamatis [11] described the methods of FMEA and its applications. Ginn et al. [12] proposed a methodology for investigating the interaction between QFD and FMEA by cross-functional and multi-disciplined teamwork. Tan [13] developed a customer-focused methodology for the built-in reliability to maximize customers' satisfaction based on the constrained resources by combining the FMEA and QFD. However, their studies are only limited to descriptive analyses for obtaining the quality and resource benefits. The methods to carry out the aggregation of QFD and FMEA are not mentioned, and the uncertainty at the product design stage is not considered, either. In this study, we extend Chen and Weng's fuzzy model [4] by introducing FMEA into the existing fuzzy QFD approach and linking phase 1 to phase 2 of QFD in determining the achievement levels of DRs and part characteristics (PCs) to maximize the customers' satisfaction.

In the following two sections, the approaches of fuzzy QFD and FMEA are introduced. In Section 4, a fuzzy linear programming model is developed to determine the achievement degrees of PCs, constrained by the need of DRs in phase 1 and the risk ratings of PCs according to the design of FMEA on DRs. A semiconductor packing example is presented to demonstrate our approach in Section 5. Finally, the concluding remarks are provided.

2. The approach of fuzzy QFD

For implementing QFD processes, a relation matrix, also called a House of Quality (HOQ), is usually used for each phase to construct the input–output relationships in determining the achievement priority or level of output variables. In practice, the major work in phase 1 of the QFD processes is to determine the achievement priority or level of DRs based on the importance of each CR, the relationships between CRs and DRs as well as among the DRs. Based on the results from the first QFD process, the similar work is performed with DRs and PCs in phase 2. Fig. 1 demonstrates the relation matrices of the two phases. Obviously, from the figure the fulfillment levels of PCs should make the DRs applicable in meeting the customers' satisfaction. In Fig. 1, $R_{1,ij}$ denotes the relation level in terms of score between the ith CR and jth DR, and $r_{1,jn}$ is the correlation score between the jth and nth DRs in the first phase of QFD. The notations k and W represent the importance score and rating in the two matrices, where $\sum k = 1$. For symbolizations, the subscripts, 1 and 2, are added to the associated variables, such as R, r, k, and W, to denote phase 1 and phase 2 of QFD, respectively, in Fig. 1 and the equations hereafter.

Considering the correlations among DRs at the first stage of QFD, Wasserman [14] proposed a formulation to calculate the normalized relationship value between CRs and DRs as

$$R'_{1,ij} = \frac{\sum_{\zeta=1}^{J} R_{1,i\zeta} \cdot r_{1,\zeta j}}{\sum_{j=1}^{J}\sum_{\zeta=1}^{J} R_{1,i\zeta} \cdot r_{1,\zeta j}}, \tag{1}$$

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