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Product design and selection using fuzzy QFD and fuzzy MCDM approaches

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ABSTRACT

Quality function deployment (QFD) is a useful analyzing tool in product design and development. To solve the uncertainty or imprecision in QFD, numerous researchers have applied the fuzzy set theory to QFD and developed various fuzzy QFD models. Three issues are investigated by examining their models. First, the extant studies focused on identifying important engineering characteristics and seldom explored the subsequent prototype product selection issue. Secondly, the previous studies usually use fuzzy number algebraic operations to calculate the fuzzy sets in QFD. This approach may cause a great deviation in the result from the correct value. Thirdly, few studies have paid attention to the competitive analysis in QFD. However, it can provide product developers with a large amount of valuable information. Aimed at these three issues, this study integrates fuzzy QFD and the prototype product selection model to develop a product design and selection (PDS) approach. In fuzzy QFD, the α-cut operation is adopted to calculate the fuzzy set of each component. Competitive analysis and the correlations among engineering characteristics are also considered. In prototype product selection, engineering characteristics and the factors involved in product development are considered. A fuzzy multi-criteria decision making (MCDM) approach is proposed to select the best prototype product. A case study is given to illustrate the research steps for the proposed PDS method. The proposed method provides product developers with more useful information and precise analysis results. Thus, the PDS method can serve as a helpful decision-aid tool in product design.

1. Introduction

Due to the fast changing demands for product functions, product life cycle has significantly decreased, compelling enterprises to develop new products that meet customer requirements in a shorter time. However, how to effectively translate customer requirements into engineering characteristics and quality factors that should be considered in product design and development is one of the important issues for modern enterprises.

So far, several product design and development approaches have been developed and applied in various areas. These methods include reverse engineering, value engineering, Taguchi method, and quality function deployment (QFD). The first three methods emphasize more on product functions and less on customer requirements and production operations. QFD, by comparison, focuses more on customer demands and coordination in the production process. Wasserman [1] and Lockamy and Khurana [2] mentioned that QFD has less technical limitation, allows inter-departmental cooperation, and offers more accurate opinions, so it is more suitable for design of new products. Thus, QFD will be employed as the product design method in this study. QFD is a method of translating the functions and quality requirements of customers into engineering

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characteristics (ECs) that are considered in product design. QFD not only helps the product design team understand customer requirements and market tendencies but also effectively shortens product development time.

Traditional QFD relies on market survey and communication with customers to obtain customer requirements (CRs). In addition, product developers usually have to use linguistic variables to set various parameters. However, the result of market survey and linguistic variables used are often uncertain or imprecise, usually resulting in biased analysis results. To solve this problem, a number of scholars have applied the fuzzy set theory to QFD and developed various fuzzy QFD approaches. These approaches include conventional QFD computation using fuzzy variables [3–5], fuzzy outranking [6], entropy [7], fuzzy tendency analysis [8], fuzzy MCDM [9], fuzzy integral [10], fuzzy analytical network process [11–13], fuzzy expected value [14,15], fuzzy goal programming [16], fuzzy expert systems [17], etc. Note that these fuzzy QFD approaches usually concentrate on obtaining the importance ranking of ECs.

From a review of related literatures, three issues can be further investigated. (1) After the importance of each EC is computed, the product design team can use important ECs to design new products desired by customers. However, in the design process, there are usually more than one prototype products. Subject to limited resources, funds, and facilities, only the best prototype product can be selected for mass production. The extant studies only focus on identifying important ECs and seldom explore the subsequent prototype product selection issue. (2) The previous studies usually used algebraic operations of fuzzy numbers to calculate the fuzzy set of each component in QFD. Theoretically, after multiplication or division of fuzzy numbers, the result should be curve-shaped rather than linear, and an error may occur. Through several multiplicative or divisional operations, the error will gradually increase, causing a great deviation of the result from the correct value. (3) Only a small number of studies [4,7,18,19] have paid attention to the competitive analysis in QFD, where design quality and sales points are included. Such analysis allows product developers to understand the strength, weakness, and quality requirement of a certain product, so it should deserve more attentions on this issue.

To solve the above issues, this study attempts to integrate fuzzy QFD and the prototype product selection model to develop a product design and selection (PDS) approach that can substantially benefit developers in product design. In fuzzy QFD, competitive analysis and correlation among ECs are considered. In addition, the α-cut operation is adopted to compute the fuzzy set of each component in QFD. In prototype product selection, in addition to ECs, production factors (such as production cost, technical difficulty, and product extensibility) will be considered as evaluation criteria. As product selection is a MCDM problem, a fuzzy MCDM method will be developed in this study. Based on the concept of linear assignment, the best prototype product can be selected for subsequent product development.

The rest of this paper is organized as follows: Section 2 briefly introduces the concepts of QFD and reviews the related works of fuzzy QFD. Section 3 discusses the concept and the detailed steps of the proposed PDS approach. Section 4 illustrates the research steps of the proposed method using a case study, and the last section concludes the present research.

2. QFD and fuzzy QFD

2.1. QFD

The QFD, originated in 1972 in Japan, has been a successful tool to assist the product design and development team (hereinafter referred to as the team) systematically in translating market research and customer requirements into the technical requirements to be met in product design. According to Bottani and Rizzi [5], QFD is composed of four successive matrices: customer requirement planning matrix, product characteristics deployment matrix, process and quality control matrix, and operative instruction matrix. Here, the current research concentrates on the first matrix (customer requirement planning matrix).

The customer requirement planning matrix, also known as "house of quality" (HOQ), is the first step in investigating customer needs and market requirements. HOQ begins with customer requirements (CRs) which are usually obtained from market survey or customer interview. The acquired CRs are translated into a list of measureable ECs. Based on the acquired CRs and ECs, the team can determine the relationships between CRs and ECs, the competitive analysis, and the correlations between ECs. The obtained information can be used to calculate the importance of ECs [20,21]. The components of HOQ are illustrated in Fig. 1. The fundamental rationale of HOQ is introduced in several publications [21,22].

Suh [23] extended the QFD principles and proposed a new approach, namely axiomatic design (AD). AD is a structured and rational design method created to improve design activities in various domains. Generally, AD consists of four design domains: customer domain, functional domain, physical domain, and process domain. Each domain is characterized by a set of information. These domains are linked through several mappings as shown in Fig. 2.

To improve a design AD uses two axioms: the independence axiom and the information axiom. The two axioms state that one should maintain the independence of all functional requirements and minimize the information content in the design, respectively. Based on the two axioms, a design matrix can be created to describe the relationship between the functional requirements and design parameters. The AD method provides a powerful design tool that can be easily understood and used by designers. AD has been successfully applied to various application areas, such as manufacturing system design [24,25], process and product design [26–28], quality function deployment [29,30], supply chain management [31], decision making [32–35], etc.