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Interfaces with Other Disciplines

Fuzzy linear programming models for NPD using a four-phase QFD activity process based on the means-end chain concept

Liang-Hsuan Chen [a,*], Wen-Chang Ko [a,b]

[a] Department of Industrial and Information Management, National Cheng Kung University, Tainan 701, Taiwan, ROC
[b] Department of Information Management, Kun Shan University, Tainan County, Taiwan, ROC

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A B S T R A C T

Quality function deployment (QFD) is a customer-driven approach in processing new product development (NPD) to maximize customer satisfaction. Determining the fulfillment levels of the "hows", including design requirements (DRs), part characteristics (PCs), process parameters (PPs) and production requirements (PRs), is an important decision problem during the four-phase QFD activity process for new product development. Unlike previous studies, which have only focused on determining DRs, this paper considers the close link between the four phases using the means-end chain (MEC) concept to build up a set of fuzzy linear programming models to determine the contribution levels of each "how" for customer satisfaction. In addition, to tackle the risk problem in NPD processes, this paper incorporates risk analysis, which is treated as the constraint in the models, into the QFD process. To deal with the vague nature of product development processes, fuzzy approaches are used for both QFD and risk analysis. A numerical example is used to demonstrate the applicability of the proposed model.

1. Introduction

Quality function deployment (QFD) is a useful customer-driven product development tool that uses a series of structured management processes to translate the customers' needs into efficient communication through the various stages of product planning, design, engineering, and manufacturing. 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. QFD provides a comprehensive and systematic approach to new product development (NPD), ensuring that new products meet customers' expectations.

Since its introduction in the late 1960s, QFD has been successfully applied in many industries to improve product design, decision making processes, and customer satisfaction (Cristiano et al., 2001a; Lager, 2005). A typical QFD process consists of four phases that relate the customer requirements (CRs) (or voice of customer) to product design requirements (DRs) (phase 1), translate the settings of DRs into critical parts characteristics (PCs) (phase 2), determine critical process parameters (PPs) (phase 3), and finally establish production requirements (PRs) (phase 4). For an NPD project, a QFD team is organized to implement all four phases of the QFD process to improve customer satisfaction. Cristiano et al. (2001b) argued that QFD has been widely accepted largely due to the logical ordering of the relationships and the fact that the four phases reflect the product development processes. However, most of the existing literature has only focused on the first phase of QFD (Chen and Weng, 2003, 2006; Kwong et al., 2007; Chen and Ko, 2008), and so the result has very limited application in a practical NPD project. This situation motivated this study to consider all four phases of the QFD activity process in an NPD.

A typical QFD diagram contains information on "whats", "hows", the relationship between the "what" and the "how", and the relationship between the "hows" themselves. For example, in phase 1, a QFD team has to collect and treat a set of "whats", i.e., CRs, create a number of appropriate "hows", i.e., DRs that affect the CRs, and then determine the relationship strength between the CRs and DRs and the relationships between the DRs themselves. Based on these inputs, the importance ratings of the "hows" will be calculated. This result is the first-stage output since it leads towards the relevant decision making later, such as the fulfillment level of DRs, resource allocation, and the following QFD analyses. In traditional QFD, the relationship strength is expressed using a point system such as 1-3-9 or 1-5-9, indicating linguistic expressions such as "weak", "moderate", and "strong", respectively. Nevertheless, QFD members usually do not have

* Corresponding author.
E-mail address: lhchen@mail.ncku.edu.tw (L.-H. Chen).

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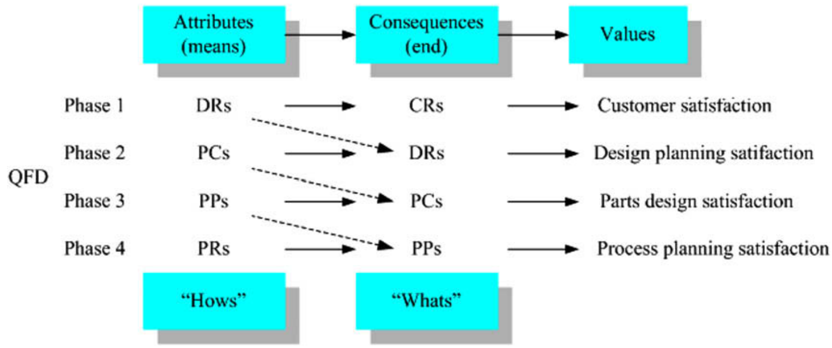

Fig. 1. A means-end chain model for the four phases of the QFD process.

sufficient knowledge and information about the influence of engineering responses on the "hows", due to the lack of information or language hedge from the "whats" (Chen and Weng, 2003). These considerations have made the application of fuzzy approaches significant in addressing diversified and imprecise problems in QFD (Chan and Wu, 2002, 2005; Chen and Weng, 2003, 2006; Kwong and Bai, 2003; Chen et al., 2006; Kahraman et al., 2006; Chen and Ko, 2008).

In addition, in the QFD process, each phase is closely related since the outcome from one phase applies the decision of the previous phase. However, how the outcomes from the latter phase make the decision of the former phase applicable is not mentioned in the existing research (Chan and Wu, 2002; Myint, 2003). In this study, considering the consistency of the QFD decision making, the concept of means-end chain (MEC) is applied to develop the QFD four-phase process to deal with the issue mentioned above. A means-end chain model (Gutman, 1982) is concerned with the relationships between attributes of a product, consequences (or benefits) accrued from the product, and customer values (satisfaction level). The attributes are created to provide the customer with certain benefits which reinforce the value to the customer. These concepts are applied in the four phases of the QFD process, and a conceptual model is shown in Fig. 1. From Fig. 1, the chain starts with the first phase of the QFD and the customer satisfaction (value) is achieved by the DRs' characteristics (i.e. design planning) which fit the CRs expectations. However, the determination of the DRs' characteristics should be realized in the next QFD process. Therefore, the role of the DRs is translated into phase 2 as the "consequences". Then, the PCs should be created to make the DRs satisfactory in phase 2. In addition, the outcomes of PCs should make the DRs applicable in phase 1 for finally realizing the customer satisfaction. This concept is also applied to the other phases to build up the decision models in the QFD process.

To decrease the risk of new product development, the risk analysis of the "hows" is usually necessary during QFD activities, and we adopted failure mode and effect analysis (FMEA) for this. FMEA is a systematic technique for identifying, prioritizing, and acting on potential failure modes before failures occur (Stamatis, 1995). Several studies have described the application of FMEA in the QFD process (Tan, 2003; Al-Mashari et al., 2005). However, the studies above were limited to only descriptive analyses. The methods of carrying out the aggregation of the QFD and FMEA are not mentioned, and the uncertainty is not considered at the product development stage, although Almannai et al. (2008) incorporated QFD and FMEA to propose a decision tool in the manufacturing system design and execution phases. In this study, we extend Chen and Weng's fuzzy model(2003) by introducing risk analysis and FMEA into the existing fuzzy QFD approach. However, Chen and Weng's fuzzy model (2003) only focused on the QFD phase 1, so that its application to a practical NPD project is limited. This paper proposes four-phase linked fuzzy QFD linear programming models for NPD projects based on the MEC concept. The proposed methodology adopted FMEA to deal with the potential risk of the "hows" in QFD phase 1, the outcomes of risk evaluation are applied to the next phase as the constraint factors of ends (or the "whats", e.g., DRs in phase 2) in determining the achievement levels of means (or the "hows", e.g., PCs in phase 2). Unlike the existing literature (Myint, 2003; Almannai et al., 2008), the risk evaluation results of the product planning stage (phase 1) are joined with the design stage (phase 2) to make the decision outcomes more applicable. This potential risk evaluation is also applied to the other phases for the engineering and manufacturing activities of an NPD project.

The objective of this paper is to propose the linked fuzzy linear programming models to determine the fulfillment levels of "hows" with the aim of achieving the determined contribution levels of "whats" in QFD processes for customer satisfaction. In addition, to deal with the potential risk of NPD, this paper incorporates FMEA into QFD processes, and treats it as the constraint factor in the model. In the following two sections, the approaches of fuzzy QFD and risk analysis are introduced. In Section 4, a set of fuzzy linear programming models are developed to determine the achievement of the "hows" in each phase of the QFD process, considering the constraints of MEC, risk, and budget. An example of a semiconductor packing case is presented to demonstrate our approach in Section 5. Finally, the concluding remarks are provided in Section 6, as well as the limitations of the study and suggestions for future research.

2. Fuzzy QFD

To implement the QFD process, a relationship matrix, also called an HOQ, is usually used for each phase to construct the relationships between the "what" and the "how" to determine the achievement priority or level of output variables. In practice, the major goal in phase 1 of the QFD process is to determine the achievement priority or level of DRs based on the importance of each CR, the relationships between CRs and DRs, and the relationships between the DRs themselves. Referring to the results from the first stage of the QFD process, similar work is performed with DRs–PCs in phase 2, PCs–PPs in phase 3, and PPs–PRs in the final phase. Since the four phases are linked, in phase 1 we denote $R_{1,ij}$ as the relationship level in terms of the score between CR_i and DR_j, and $r_{1,jJ}$ is the correlation score between DR_j and DR_J. Similar notations are also used in the other phases.

Considering the relationships between the DRs themselves in phase 1 of QFD, and considering the imprecise nature of the relationships, Chen and Weng (2003) proposed a fuzzified formulation based on Wasserman (1993) to calculate the normalized fuzzy relationship value between CRs and DRs as