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A new mixed integer linear programming model for product development using quality function deployment

Elif Kılıç Delice [a,*], Zülal Güngör [b]

[a] Industrial Eng. Dept., Atatürk University, 25240 Erzurum, Turkey
[b] Industrial Eng. Dept., Gazi University, 06570 Maltepe-Ankara, Turkey

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ABSTRACT

Quality function deployment (QFD) is a product development process performed to maximize customer satisfaction. In the QFD, the design requirements (DRs) affecting the product performance are primarily identified, and product performance is improved to optimize customer needs (CNs). For product development, determining the fulfillment levels of design requirements (DRs) is crucial during QFD optimization. However, in real world applications, the values of DRs are often discrete instead of continuous. To the best of our knowledge, there is no mixed integer linear programming (MILP) model in which the discrete DRs values are considered. Therefore, in this paper, a new QFD optimization approach combining MILP model and Kano model is suggested to acquire the optimized solution from a limited number of alternative DRs, the values of which can be discrete. The proposed model can be used not only to optimize the product development but also in other applications of QFD such as quality management, planning, design, engineering and decision-making, on the condition that DR values are discrete. Additionally, the problem of lack of solutions in integer and linear programming in the QFD optimization is overcome. Finally, the model is illustrated through an example.

1. Introduction

Quality function deployment (QFD), which is a widely used customer-driven product development method originated in the late 1960s in Japan by Akao (1990). In 1972, QFD was implemented at the Kobe shipyards of Mitsubishi Heavy Industries Ltd. Its application was followed by successful implementations throughout Japan (e.g. at Toyota). QFD was introduced to US with its application in Ford Motor Company, and has played an important role since then at companies (Prasad, 1998).

QFD is a well-known planning methodology for translating customer needs (CNs) into relevant design requirements (DRs). Generally QFD utilizes four sets of matrices: houses of quality (HOQ) to relate the CNs to product planning, parts deployment, process planning and manufacturing operations (Hauser & Clausing, 1998). QFD develops a new product, or a new version of an existing product to maximize customer satisfaction by integrating marketing, design engineering, manufacturing, and other related functions of an organization considering such criteria as cost and technical difficulty. In addition to these, QFD has increasingly been applied to transportation and communication, electronics and electrical utilities, software systems, manufacturing, services, education and research, and many other industries including aerospace, construction, packaging and textile (Chan & Wu, 2002).

A comprehensive review of the related literature reveals many studies on QFD analysis. However, there are few studies where values of DRs are taken as discrete. What is more, there seems to be a lack of integer and linear programming solutions in the QFD optimization (Lai, Xie, & Tan, 2005). Therefore, the present study proposes a new QFD optimization approach combining mixed integer linear programming (MILP) model and Kano model. The approach is based on the proposed model by Lai, Xie, and Tan (2004), and it focuses on the field of product development.

This paper is organized as follows. Section 2 gives a short literature review. Section 3 presents a new QFD optimization approach and describes its mathematical modeling. An example is given to demonstrate our approach in Section 4. Finally, conclusions and discussions are provided in Section 5. The notations used in the paper are listed in Appendix A.

2. Literature review

Chan and Wu (2002) and Carnevalli and Miguel (2008) present an extensive literature review of general applications of QFD. The present study using the MILP model, which is an optimization model, and Kano model reviews the QFD literature with a specific focus on the two models in the following subsections.

* Corresponding author. Tel.: +90 312 2317400/2823; fax: +90 312 2308434.
E-mail address: elifkilic@gazi.edu.tr (E.K. Delice).

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2.1. Optimization methods in QFD literature

Different optimization methods have been applied in the field of QFD to maximize customer satisfaction under cost and other resource constraints. For instance, linear programming model is used to select the mix of DRs. This model is generally used to allocate resources to the different DRs in order to maximize the overall customer satisfaction (Askin & Dawson, 2000; Lai et al., 2004; Lai, Xie, & Tan, 2007; Moskowitz & Kim, 1997; Sohn & Choi, 2001; Tang, Fung, Xu, & Wang, 2002; Wasserman, 1993). Integer programming is also used to optimize product design (Park & Kim, 1998). This approach attaches the greatest attention to the most important DR. However, effort is devoted to the selection of DRs to the extent that other DRs are overlooked. Furthermore, a new approach is proposed to address the difficulties due to the uncertainty of data (Zhou, 1998). In the proposed approach, DRs are prioritized through a fuzzy ranking procedure and the improvements are optimized using a MILP. In other study, a MILP model is proposed to determine the DRs to be considered in designing a product. The coefficients of the objective function are also obtained from a fuzzy analytic network process (ANP) approach (Kahraman, Ertay, & Büyüközkan, 2006). Additionally an integrated approach using zero–one goal programming and ANP is also proposed to determine the DRs by Karsak, Sozer, and Alptekin (2002). In further studies, fuzzy linear programming (Chen & Weng, 2003) and fuzzy goal programming models are put forward to determine the fulfillment levels of the DRs (Chen & Weng, 2006), and a nonlinear mathematical programming model is developed to determine the optimal DRs (Dawson & Askin, 1999; Fung, Tang, Tu, & Wang, 2002). In addition to these, a multi-objective mathematical programming model is presented to convert qualitative information into quantitative parameters and then to combine these data with the other quantitative data (Erol & Ferrell, 2003). Finally, Lai et al. (2005) proposed a dynamic programming approach to solve the optimization problem where values of the DRs are discrete, and they employed a linear physical programming (LPP), a new and effective multi-objective optimization method, to maximize overall customer satisfaction in product design (Lai, Xie, & Tan, 2006).

2.2. Kano model in QFD literature

The Kano model is developed by Kano and other researchers (Kano, Seraku, Takahashi, & Tsuji, 1984). It is a unique and flexible model of product development for characterizing CNs. In many studies, the Kano model is used to assess customer attributes (see, for example, King, 1995; CQM, 1993; Clausing, 1994; Cohen, 1995). The Kano model has been applied particularly to new product development (Matzler & Hinterhuber, 1998), new service creation (NSC) (Bhattacharyya & Rahman, 2004) and to the development of various online services, such as web site (Zhang & von Dran, 2001), internet community (Szmigin & Reppel, 2004), and online ticketing (Nilsson-Witell & Fundin, 2005). A variation of this methodology has also been applied a to cockpit weather information system (CWIS) design (Sireli, Kauffmann, & Ozan, 2005).

In the Kano model certain weights are assigned to different customer attributes in the QFD field. According to Islam and Liu (1995), CNs can be divided into three subgroups: basic, one-dimensional and excitement. The weight calculated by an analytic hierarchy process is multiplied to adjust the raw importance for each requirement. Similarly, Robertshaw (1995), who uses the dual importance grid, classified the type of Kano element and proposed a re-prioritization of CNs. Here, to deliver what is expected is the top priority; the second highest priority is what is specified; the lowest priority is to provide the attractive elements. Likewise, Gerson's study (2003) uses a modified Kano method to determine the degree to which customers consider an attribute to be attractive or must-be and demonstrates how to integrate it into the planning matrix of the QFD. Still another study analyzes customer satisfaction based on the Kano model and stresses the importance of achieving product innovation in exceeding the customer expectations (Tan, Tang, & Forrester, 2004). The present study adopts an integrative approach, in which the Kano model and the fuzzy model are combined into the matrix of QFD and CNs weights are adjusted (Lee, Sheu, & Tsou, 2008).

In the QFD literature, as well as the abovementioned applications of the Kano model, other studies exist in which the Kano model is used together with optimization methods. For example, an approach combining the Kano model with QFD is proposed to provide a product design optimization method (Lai et al., 2004). This method uses the Kano model to analyze CNs and QFD to translate CNs into product design. The design was optimized using a linear programming model under cost constraints. In addition, this approach is applied in optimizing PC design (Lai et al., 2007).

This paper is organized as follows. Section 2 gives a short literature review on QFD optimization methods and Kano model. Section 3 introduces a new QFD optimization approach and describes its mathematical modeling. Section 4 presents a case to demonstrate the approach adopted in the present study. Finally, Section 5 covers conclusions and discussions. The notations used in the paper are listed in Appendix A.

3. A new approach to QFD optimization

In this paper, a new QFD optimization approach is suggested combining MILP model and Kano model. This approach is originated from a model proposed by Lai et al. (2004). Different from other studies in the literature, the present study suggest the new approach to obtain the optimized solution from a limited number of alternatives of DRs the values of which can be discrete because, in real world applications, the values of DRs are often discrete instead of continuous. For example, the dimensions of computer monitors could not get 15.75″, 16.25″. Their dimensions have real values of about 15″, 17″ or 19″. That is, the values of computer monitor dimensions have discrete range. They do not have a continuous range.

For the reasons given above, dynamic programming is proposed to solve this type of optimization problem where values of the DRs are discrete and to overcome the problem of lack of solutions in integer and linear programming (Lai et al., 2005) because, although integer and linear programming perform well in certain circumstances, there are still some problems with them. Integer programming pays the greatest attention to the most important DRs. However, effort is devoted to the selection of DRs to the extent that other DRs are overlooked. The disposed DRs may greatly hinder customer satisfaction. In linear programming, the values of the DRs are often assumed to be any point along a continuous range. In this method, the actual relationships between DRs-customer satisfaction and DRs-cost can at times be difficult to represent (Lai et al., 2005). In our study, the abovementioned gaps are filled by using a new MILP model.

In this study, the Kano model is implemented to determine customer satisfaction (CS) coefficient and the customer dissatisfaction (DS) coefficient of each CN. Then, these coefficients are used in the proposed MILP model.

3.1. Kano model

The Kano model provides an effective way of categorizing CNs and helps understand the nature of these needs. The Kano model divides the product or service attributes as following categories (Fig. 1), each of which affects customers in a different way as fol-