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Using quality function deployment for collaborative product design and optimal selection of module mix

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ABSTRACT

In response to fast-growing and rapidly-changing markets, launching new products faster than competitors cannot only assist firms in acquiring larger market share but also reducing development lead time, significantly. However, owing to its intrinsically uncertain properties of managing NPD (new product development), manufacturing companies often struggle with the dilemma of increasing product variety or controlling manufacturing complexity. In this study, a fuzzy MCDM (multi-criteria decision making) based QFD (quality function deployment) which integrates fuzzy Delphi, fuzzy DEMATEL (decision making trial and evaluation laboratory), with LIP (linear integer programming) is proposed to assist an enterprise in fulfilling collaborative product design and optimal selection of module mix when aiming at multi-segments. In particular, Fuzzy Delphi is adopted to gather marketing information from invited customers and their assessments of marketing requirements are pooled to reach a consensus; fuzzy DEMATEL is utilized to derive the priorities of technical attributes in a market-oriented manner; and LIP is used to maximize product capability with consideration of supplier's budget constraints of manufacturing resources. Furthermore, a real case study on developing various types of sport and water digital cameras is demonstrated to validate the proposed approach.

1. Introduction

In an era of customer-oriented global economy, dominating the majority market with a single product line becomes very challenging and almost infeasible for most companies (Hsiao & Liu, 2005). Traditionally, to satisfy market majorities, companies considered providing products with high quality, low cost, fast delivery and courteous after-sales service at most. Nowadays, owing to fiercely competitive environments and rapidly changing demand, the capability and the speed of developing niche products and launching them into the niche segments gradually dominate the competition paradigm, particularly when a transition has been shifting from "supply push" to "demand pull" (Jiao, Ma, & Tseng, 2003). To put it another way, "mass customization" embarks a new paradigm for modern manufacturing industries since it treats each customer as an individual and attempts to provide "tailor-made" featured products that was only offered in the pre-industrial "craft" era.

Over the past two decades, numerous publications originated from different disciplines have witnessed in the field of customer requirement management (Jiao & Chen, 2006). For example, various fields such as marketing research, consumer behavior, collaborative design, and concurrent engineering, attempt to contribute to different stages for new product development (NPD). Among them, marketing research and consumer behavior emphasize the front issues relevant to collecting the information of customer preference via specific channels. In contrast, collaborative design and concurrent engineering focus on utilizing a systematic and parallel approach for integrating a wide spectrum of product design and related manufacturing processes (Lin, Wang, Chen, & Chang, 2008). Although high product variety does stimulate product sales, companies still inevitably face the trade-offs between the diversity of customer needs and numerous adverse effects, such as larger inventory cost, longer cycle time and expensive research investment.

As a result, it is very imperative for companies to keep high flexibility while incurring limited manufacturing cost, concurrently. In practice, two common techniques have been proposed to tackle the above-mentioned issue, including product family architecture (Jiao & Tseng, 1999; Moon, Simpson, & Kumara, 2010) and modular product or product family design (Hsiao & Liu, 2005; Kreng & Lee, 2004). Modular product design offers a feasible way by developing a product architecture, in which physical relationships across modules are limited while functional relationships among components within a module are coherent. Furthermore, product family design based on a standard platform usually provides a cost-effective way to develop highly related but differentiated

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products. By sharing/reusing physical manufacturing resources and intangible human capitals, companies can efficiently balance the benefit and cost for NPD.

Based on previous studies, most of them are deficient in constructing a systematic approach to assist companies in achieving mass customization while keeping reasonable manufacturing cost. In this study, a fuzzy MCDM based QFD (quality function deployment) is proposed to fulfill collaborative product design and optimal selection of module mixes when aiming at multi-segments. Moreover, this paper contributes to this domain by presenting the following merits:

- QFD provides a communication platform to gather different opinions between industrial experts and even among customer individuals.
- QFD is capable to transform intangible marketing requirements (MRs) into measurable technical attributes (TAs) and to accommodate the dependences between MRs and TAs and the correlations among themselves.
- In additional to deriving the weights of MRs and TAs, the proposed fuzzy MCDM based QFD could further identify the optimal module mix (product variety) for a specific market segment.

The remaining of this paper is organized as follows. Section 2 overviews the related works and Section 3 introduces the proposed framework which integrates fuzzy Delphi, fuzzy DEMATEL with LIP (linear integer programming). A real example regarding collaborative design for various sport & water digital cameras is illustrated in Section 4. Conclusions are drawn in Section 5.

2. Related works

Quality function deployment (Akao, 1990) originated in Japan in the 1970s has been widely applied to various industries for product development, concept evaluation, service design, and competitor benchmarking. Basically, customers' desires on a specific product or service can be represented by a set of intangible marketing requirements (MRs). Thereafter, a series of technical attributes (TAs) that impact on MRs need to be determined and realized for product development or service design. Typically, the conventional QFD consists of the following four phases (Chan, Kao, Ng, & Wu, 1999; Lin, Cheng, Tseng, & Tsai, 2010): phase one translates marketing requirements into technical attributes; phase two translates technical attributes into part characteristics; phase three translates part characteristics into manufacturing operation, and phase four translates manufacturing operations into production requirements. Specifically, at phase one of QFD, the so-called HoQ (house of quality) provides a communication platform to fuse diverse opinions among cross-functional team members (see Fig. 1).

To fast understand the research trend regarding QFD, representative publications are reviewed and listed below. First, to determine the importance degrees of MRs, AHP (analytical hierarchy process)/fuzzy AHP (Kwong & Bai, 2002, 2003), fuzzy Delphi (Chen & Ko, 2008; Karsak, 2004), and fuzzy group decision (Büyüközkan, Feyzioğlu, & Ruan, 2007; Sein, Ho, Lai, & Chang, 1999) have been suggested, respectively. Second, to improve the weakness of AHP/fuzzy AHP, numerous papers adopt ANP (analytical network process)/fuzzy ANP to consider the dependences between MRs and TAs and the correlations among themselves, such as Karsak, Sozer, and Alptekin (2002), Büyüközkan, Ertay, Kahraman, and Ruan (2004), Kahraman, Ertay, and Büyüközkan (2006), Lin et al. (2010), and Lee, Kang, Yang, and Lin (2010). Recently, various optimization schemes with consideration of budget cost or resource

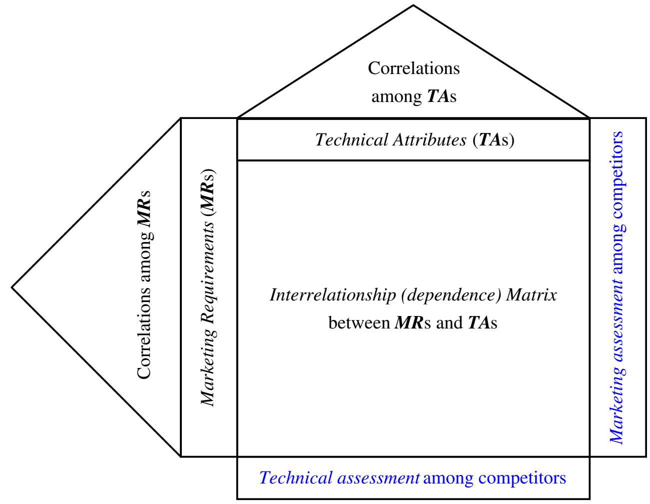

Fig. 1. A general framework for the conventional HoQ (house of quality).

constraints have been incorporated into the QFD. For example, zero-one goal programming or fuzzy goal programming is formulated to determine the level or a mix of design requirements (Chen & Weng, 2006; Karsak, 2004; Karsak et al., 2002). A two-phase QFD which combines ANP/fuzzy ANP with goal programming is utilized to determine the optimal varieties of product attributes for distinct market segments (Lee et al., 2010; Liu & Hsiao, 2006; Park, Shin, Insun, & Hyemi, 2008).

After reviewing the above-mentioned studies, several critical shortcomings are found and listed below:

- A systematic approach to efficiently identify the causal impacts of MRs on TAs and the correlations among themselves is imperative, yet, rarely addressed and incorporated into the entire decision-making process.
- AHP/fuzzy AHP (Saaty, 1980) are capable to determine the weights of "independent" criteria, but they are limited to handle a scenario in which the interdependences exist among criteria or the number of criteria is over a reasonable threshold.
- ANP/fuzzy ANP (Saaty, 1996) are commonly adopted to accommodate the complicated interdependences among criteria, but they might be infeasible in processing a scenario in which numerous criteria appear on a hierarchy.

Suppose that there are n mutually interdependent criteria (associated with an n-order matrix), to completely describe their interrelationships among all criteria, we might need to conduct up to $n^2(n-1)/2(n \times C_2^n)$ times of pair-comparisons for obtaining

Table 1
An overall comparison among AHP, ANP, DEMATEL and proposed method.

	AHP	ANP	DEMATEL	Proposed
Handling an independent hierarchy structure	Yes	Yes	Yes	Yes
Handling an interdependent network structure	No	Yes	Yes	Yes
Conducting pairwise comparisons among criteria	Limited	Tedious	Not necessary	Not necessary
Deriving the importance weights of criteria	Yes	Yes	No	Yes
Handling numerous criteria within the same decision level	Limited	Limited	Yes	Yes
Identifying causal relationships among criteria	No	No	Strong	Strong