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Use of ANP weighted crisp and fuzzy QFD for product development

Selim Zaim [a], Mehmet Sevkli [b], Hatice Camgöz-Akdağ [c], Omer F. Demirel [b], A. Yesim Yayla [d], Dursun Delen [e,*]

[a] Department of Industrial Engineering, Istanbul Technical University, Istanbul, Turkey
[b] Department of Industrial Engineering, Fatih University, Istanbul, Turkey
[c] Department of Management Engineering, Istanbul Technical University, Istanbul, Turkey
[d] Department of Mechanical Engineering, Marmara University, Istanbul, Turkey
[e] Department of Management Science and Information Systems, Oklahoma State University, Tulsa, Oklahoma, USA

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ABSTRACT

Quality Function Deployment (QFD) is a popular planning method often used to transform customer demands/requirements into the technical characteristics of a new or improved product or service. In order to better capture (and represent) the multifarious relationships between customer requirements and technical characteristics, and the relative weights among customer requirements, in this study a hybrid analytic network process (ANP)-weighted fuzzy methodology is proposed. The goal is to synthesize renowned capabilities of ANP and fuzzy logic to better rank technical characteristics of a product (or a service) while implementing QFD. To demonstrate the viability of the proposed methodology a real-world scenario, where a new equipment to squeeze the polyethylene pipes to stop the gas flow without damaging the pipes, is developed. The ranking of technical characteristics of the product is calculated using both crisp and fuzzy weights for illustration and comparison purposes.

1. Introduction

Successful and innovative product (or service) development is highly correlated with the company's success and reason for existence. It is imperative that a company's main purpose for existing is to provide goods and/or services to meet and even exceed the expectations of their customers. In order to be successful, companies must choose goods and/or services in which to establish a competitive advantage, and by doing so, differentiate themselves from their competitors (Smith, 2011). Product quality improvements are crucial factors for companies to gain and sustain competitive advantage. The Profit Impact of Marketing Strategy (PIMS) claims that improvements in product quality go along with customer loyalty, higher market share and higher profits (Lemmink & Kasper, 1994). Innovation and New Product Development (NPD) are considered important ingredients for economic development (Schumpeter, 1934) corporate growth and survival (Drucker, 1985).

There are many manufacturing and design techniques and strategies companies utilize to develop new products (Biswas & Sarker, 2008; Browning & Heath, 2009; Cavaleri, 2008; Chan & Kumar, 2009; Grewal, 2008). Some businesses may organize product development teams that are responsible for new product from conceptualization to getting the final product in store shelves (Smith & Offodile, 2008). While developing new products or improving existing products companies can choose to use one or more of the design methods, such as robust design (Boylan & Cho, 2013), modular design (Chang, Wang, & Wang, 2013), Computer Aided Design (CAD) (Naranje & Kumar, 2014), 3-D object modeling (Alves & Bártolo, 2008), Computer-Aided Manufacturing (CAM) (Kimura, 2013), virtual reality (Ore, Wiktorsson, Hanson, & Eriksson, 2014), value analysis (Smals & Smits, 2012) and Quality Function Deployment (QFD) (Chen, Chen, & Lın, 2004; Graner & Mißler-Behr, 2013; Li, 2013). According to the study conducted by Li et al. (2011), companies use a variety of methods to determine the final importance rating of customer requirements; these methods include point scoring scale (Hauser & Clausing, 1988), conjoint analysis (Griffin & Hauser, 1993), Analytic Hierarchy Process (AHP) (Armacost, Componation, Mullens, & Swart, 1994; Govers, 1996; Ho, 2008; Lu, Madu, Kuei, & Winokur, 1994; Wasserman, 1993), fuzzy AHP (Chan, Kao, Ng, & Wu, 1999; Kwong & Bai, 2002; Kwong & Bai, 2003; Wang, 1999), analytic network process (ANP)

* Corresponding author. Address: Department of Management Science and Information Systems (MSIS), 700 North Greenwood Avenue, Suite: NH341, Spears School of Business, Oklahoma State University, Tulsa, OK 74106, USA. Tel.: +1 (918) 594 8283; fax: +1 (918) 594 8281.

E-mail address: dursun.delen@okstate.edu (D. Delen).

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(Ertay, Kahraman, & Ruand, 2005; Karsak, Sozer, & Alpteki, 2002; Partovi, 2006; Partovi, 2007; Partovi & Corredoira, 2002; Raharjo, Brombacher, & Xie, 2008), fuzzy ANP (Buyukozkan, Feyzioğlu, & Ruan, 2004; Kahraman, Ertay, & Buyukozkan, 2006; Liu & Wang, 2010), fuzzy weighted average (Chen, Fung, & Tang, 2006; Khoo & Ho, 1996), gray model (Wu, 2006), evidential reasoning based approach (Chin, Wang, Yang, & Poon, 2008), rough set based approach (Li, Tang, Luo, & Xu, 2009; Zhai, Khoo, & Zhong, 2007; Zhai, Khoo, & Zhong, 2009), rough set enhanced fuzzy approach (Zhai, Khoo, & Zhong, 2008) and group decision- making approach (Ho, Lai, & Chang, 1999; Liu & Wu, 2007; Liu & Wu, 2008). Li et al. (2011) also added that in most of the QFD research studies, relationships and correlations among/between the features and specifications are determined using simple scaling methods. In order to more accurately capture and represent these relationships and correlations, several researchers have proposed the use advanced ranking/scaling methods, such as swing method (Park & Kim, 1998), Design Of Experiment (DOE) (Dawson & Askin, 1999), Taguchi method (Kumar, Barua, & Gaindhar, 2000), linear partial ordering approach (Han, Kim, & Choi, 2004), fuzzy regression (Fung, Chen, & Tang, 2006; Kim, Moskowitz, Dhingra, & Evans, 2000), evidential reasoning based approach (Chin et al., 2008) and ANP (Abbasi, Hosnavi, & Tabrizi, 2013; Horenbeek & Pintelon, 2014; Lee, Wu, Hu, & Flyn, 2013).

A popular and proven way to determine what customers want and how to channel their wants into a product design is through the QFD. According to Heizer and Render (2008), QFD helps to translate customer needs into engineering specifications for a product by prioritizing each product attribute/feature while simultaneously setting development targets for the same product. The House of Quality (HOQ), for example, is a popular tool used by QFD wherein visually appealing graphical illustrations are used to define the relationships between customer desires and the product features (Smith, 2011). The use of QFD has gained extensive international support for helping decision-makers (DMs') in product planning and improvement (Akao & Mazur, 2003; Chan & Wu, 2002; Chien, Chen, & Peng, 2010; Hajji, Mhada, Gharbi, Pellerin, & Malhame, 2011; Karipidis, 2011; Lin, Cheng, Tseng, & Tsai, 2010b; Lin, Yang, Chan, & Sheu, 2010a; Wong & Lai, 2011; Xie, Tan, & Goh, 2003). AHP has been used as the quantitative tool to augment QFD (Cheng & Lin, 2002). An integrated QFD–AHP approach can be successfully used in identifying and prioritizing customer requirements, dealing with complex situations, and rank ordering product features (Fiorenzo, 2001).

Research on fuzzy QFD has received a considerable amount of attention in the last couple of dacades (Harding, Popplewell, Fung, & Omar, 2001; Temponi, Yen, & Tiao, 1999), and made substantial progress. Khoo and Ho (1996) proposed an approach centred on the application of possibility theory and fuzzy arithmetic to address the ambiguity in QFD operations (Bevilacqua, Ciarapicab, & Giacchettab, 2006). Fuzzy approaches can be applied to formulate the relationships between customer requirements and engineering design requirements, and among design requirements (Cheng & Weng, 2006; Shen, Tan, & Xie, 2001). Ramasamy and Selladurai (2004) developed a fuzzy QFD for translating the Voice of Customer (VOC) into engineering characteristics. Yang, Wang, Dulaimi, and Low (2003) have proposed a fuzzy QFD system for buildable designs based on mechanisms of the conventional QFD methodology. The differences between the fuzzy QFD system and the traditional QFD methodology is that the QFD relevant data are expressed and represented as linguistic terms rather than crisp numbers, and the linguistic data is processed by algorithms embedded in the system's internal environment (Mehrjerdi, 2010).

In addition to AHP, the ANP technique, also developed by Saaty, is a generic form of the AHP that allows for more complex, interdependent, relationships, and feedback among elements in the hierarchy (Saaty, 2001). The ANP has been proposed as a suitable Multi Criteria Decision Analysis (MCDA) tool to evaluate multiple alternatives during the conceptual planning and design of remedial countermeasures (Promentilla, Furuichi, Ishii, & Tanikawa, 2006; Promentilla, Furuichi, Ishii, & Tanikawa, 2005). Due large to its late arrival, and not being recognized as a competitive tool, the ANP technique is not nearly as prominent and widely used in the MCDA literature as the AHP technique (Partovi, 2001). According to Shee, Tzeng, and Tang (2003), most of the traditional Multi Attribute Decision Making methods (MADM) are based on the additive concept along with the independence assumptions, but each individual criterion is not always completely independent. Even though AHP has a number of benefits it still has some inherent limitations due to its hierarchical representation (Anand & Kodali, 2009). Sarkis and Talluri (2002) have listed the limitations of AHP such as; each element in the hierarchy is supposed to be independent and a relative ratio scale of measurement is derived from pair-wise comparisons of the elements in a level of the hierarchy with respect to an element of the preceding level. However, in many cases, there is interdependence among criteria and alternatives (Sarkis & Talluri, 2002). The second limitation Sarkis and Talluri (2002) mentioned was that AHP employs a unidirectional hierarchical relationship among decision levels, which implies no influence of lower levels on the upper levels. But it may be possible for the components of the two levels to influence each other. These relationships cannot be evaluated using AHP (Sarkis & Talluri, 2002). To overcome these problems, Anand and Kodali (2009) suggested to use ANP in solving the complex decision problem for their case.

The local priorities in ANP are established in the same manner as they are in AHP using pair wise comparisons and judgments (Promentilla, Furuichi, Ishii, & Tanikawa, 2008). However, the super matrix approach, which became popularly known as the ANP approach, is becoming an attractive tool to understand more of the complex decision problem as it overcomes the limitation of the AHP's linear hierarchy structure (Saaty, 1996; Saaty, 2001). ANP also allows for the consideration of the interdependencies among and between the levels of attributes and alternatives (Partovi, 2001). To strengthen its capabilities, Partovi (2001) added that ANP does involve relationships hierarchically but does not require a strict hierarchical structure as AHP. Buyukozkan et al. (2004) used fuzzy ANP to prioritize design requirements by taking into account the degree of the interdependence between the customer needs and design requirements and the inner dependence among them. Mikhailov and Singh (2003) used fuzzy ANP and its application to the development of decision support systems. The aim of fuzzy ANP is to capture the 'fuzziness' or the vagueness-type uncertainties in the evaluation of remedial countermeasures particularly at the initial phase of remediation planning. (Promentilla et al., 2008).

AHP and ANP are often used in combination with other methods. For instance, Karsak et al. (2002) combined goal programming approach with ANP for product planning in QFD. Bevilacqua et al. (2006) indicated that in traditional QFD, most of the input variables are assumed to be precise and are treated as crisp numerical data. However, linguistic variables expressed in fuzzy numbers seem more appropriate for describing those inputs in QFD (Bevilacqua et al., 2006). Hisdal (1988) study indicated that in the context of rank-ordering requirements and specifications, fuzzy logic can handle inexact information and verbal variables in a mathematically well-defined way which simulates the processing of information in natural-language communication. Some researchers (Buyukozkan et al., 2004; Kahraman et al., 2006, 2004b) applied a fuzzy ANP approach to QFD problems. Their method is an extension of fuzzy AHP (FAHP) approach proposed by Chang (1996), which derives crisp local priorities from fuzzy comparison matrix using the extent analysis method and possibility