Computers & Industrial Engineering 91 (2016) 178–187

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A group multi-granularity linguistic-based methodology for prioritizing engineering characteristics under uncertainties ☆

Zengqiang Wang [a,*], Richard Y.K. Fung [b], Yan-Lai Li [c], Yun Pu [c]

[a] School of Economics and Management, Southwest Jiaotong University, Chengdu, Sichuan 610031, People's Republic of China
[b] Department of Systems Engineering and Engineering Management, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong, China
[c] School of Transportation and Logistics, Southwest Jiaotong University, Chengdu, Sichuan 610031, People's Republic of China

ARTICLE INFO

Article history:
Received 30 January 2015
Received in revised form 20 July 2015
Accepted 16 November 2015
Available online 2 December 2015

Keywords:
Quality function deployment
House of quality
Customer requirements
Engineering characteristics
Unbalanced linguistic label set
Group decision making

ABSTRACT

Quality Function Deployment (QFD) is a customer driven tool for product development. Prioritizing Engineering Characteristics (ECs) is a crucial stage in QFD. However, the complex and imprecise factors in QFD present many difficulties for the analysis process of ranking ECs. Even though different techniques have been applied to determine the importance of ECs, they do not fully express all the preferences involved, which could affect the preciseness of results. To address the vague information at the early stage of product development effectively, this paper presents a group multi-granular linguistic-based approach to enable customers or developers to express their preferences using different linguistic label sets. Using different linguistic label sets although makes the process more complicated, it is more meaningful and more practical. Apparently, the proposed method may not only reflect the vague information effectively, but also avoid the risk of information loss. The proposed approach uses a two-phase framework to determine the priority of CRs and evaluate the priority of ECs. A case example is given to illustrate the feasibility and validity of the proposed method. The proposed approach is superior to the existing approach in terms of robustness.

1. Introduction

Nowadays economic globalization and technological innovations have an immense impact on the manufacturing processes. Companies have been facing radical challenges of having to continuously improve their competitiveness and competitions in product development and production. Thus, new product development technologies are employed to enhance the satisfaction of customers. Quality Function Deployment (QFD) is a method of translating Customer Requirements (CRs) into the suitable Engineering Characteristics (ECs), characterized by reflecting "the voice of customers" to the final product through various stages of product planning, design and manufacture (Akao & Mazur, 2003; Carnevalli & Miguel, 2008).

A typical QFD process can be expressed in four matrices i.e., product planning, parts planning, process planning, and production planning (Fung, Tang, Tu, & Wang, 2002; Li, Tang, Luo, Yao, & Xu, 2009, 2010). The first matrix is also known as House of Quality (HoQ), which is considered to be an important tool to obtain accurate information (Chen & Ko, 2008; Li, Chin, & Luo, 2012a). Many manufacturers have found the HoQ is a practical tool for understanding customer requirement. Generally speaking, within the structure of HoQ, it is impossible to consider all ECs because of time and budget constraints, as well as technological limitations (Chen et al., 2004; Li et al., 2012a). Thus, determining the ratings of ECs by utilizing the information available is a critical process in constructing the HoQ (Chen, Fung, & Tang, 2005; Kim, Kim, & Min, 2007). Products can be designed to meet or surpass customer needs depending on the ratings. However, since the prioritization of ECs focuses on the early stage of product development, taking into account the uncertainty of input information is important and necessary. In addition, the decision-makers involved in QFD, consisting of some customers or developers, are usually organized to determine the final priority ratings of CRs and the relationship between CRs and ECs. The subsequent decisions without considering these problems will be improper because of the variability due to uncertainty.

The earliest method used to determine the priority of ECs is expressed in a 5-point or 7-point likert scale (Chan & Wu, 2002, 2005), but the data available for prioritizing ECs may be imprecise and limited (Chen, Fung, & Tang, 2006). Thus, customers or developers normally cannot express their preferences in crisp values.

☆ This manuscript was processed by Area Editor Imed Kacem.

* Corresponding author. Tel./fax: +86 28 87600822.
E-mail address: wzqlinger@126.com (Z. Wang).

http://dx.doi.org/10.1016/j.cie.2015.11.012
0360-8352/

Some studies (Bhattacharya, Sarkar, & Mukherjee, 2005; Ho, 2008; Lin, Cheng, Tseng, & Tsai, 2010) adopt Analytic Hierarchy Process (AHP) to address the priority problem. There are also many studies where Analytic Network Process (ANP) is applied to rank the order of ECs (Lee, Kang, Yang, & Lin, 2010Partovi, 2006, 2007; Raharjo, Brombacher, & Xie, 2008). In practice, the calculations in these methods tend to be complex and rely on the consistency of the outcomes, but the checking process is not always a necessary condition for ranking (Li, Huang, Chin, Luo, & Han, 2011).

Moreover, the perception of customers and developers is often subjective and ambiguous. In order to overcome these difficulties, fuzzy numbers are used to express their assessment. Some studies combine fuzzy set theory and some of the above methods to prioritize ECs (Chen et al., 2006; Liu & Wang, 2010). Fuzzy AHP with an extent analysis approach is proposed to deal with the imprecise and vague information in QFD (Kwong & Bai, 2002). Fuzzy logic and AHP based on QFD are employed to rank the ECs of Iran mobile celluar telecommunication (Khademi-Zare, Zarei, Sadeghieh, & Saleh Owlia, 2010). Wu (2011) develops a fuzzy measurable HoQ model to handle subjective evaluation and incomplete information of the early development stage. An integrated approach is applied to evaluate and select the optimal third-party logistics service providers, combining QFD, fuzzy set theory, and AHP (Ho, He, Lee, & Emrouznejada, 2012). An innovative fuzzy-QFD method is adopted to develop new products according to characterizing CRs (Bevilacqua, Ciarapica, & Marchetti, 2012; Kwong, Wong, & Chan, 2009), the outcomes illustrate that the availability of such combined technique also can test the quality of existing products. Since the results obtained from the use of fuzzy numbers may be improved largely, the model based on fuzzy QFD has been widely applied to tackle the uncertainties in HoQ (Chen et al., 2004a; Pawlak & Skowron, 2007). Apparently, fuzzy numbers could be used to express decision makers' preferences. Nevertheless, the methods have some problems in practical applications, for example, the effectiveness of the operation still depends on the subsequent defuzzification process, because the final priority of ECs is determined based on numerical scales rather than fuzzy numbers, which may involve information loss (Fung, Chen, & Tang, 2006). In addition, suitable membership functions are difficult to determine (Zhai, Khoo, & Zhong, 2008). For convenience, certain simple but not efficient functions are usually employed for analyzing the problem (Zha, Sriram, & Lu, 2005).

Generally, ranking ECs needs inputs from many parties in a collaborative decision-making process. Therefore, the prioritization of ECs is essentially a typical group decision-making problem. Some researches have focused on handling the issue of ranking ECs by utilizing group decision-making methods. For example, considering human perception and heterogeneity in QFD, a novel fuzzy group decision-making method that integrates a fuzzy weighted average method is incorporated into the construction process of the HoQ (Kwong, Ye, Chen, & Choy, 2011). A fuzzy multiple objective programming approach is applied to determine the level of fulfillment of design requirements (Karsak, 2004). However, customers or developers are normally treated equally in most previous work, while the importance weight of each customer or developer may be overlooked.

Even though different techniques and fuzzy theory have been applied in industries during product planning and development, they do not fully reveal all the preferences involved, because the development process often has to decode the vague and imprecise input provided by target customers or developers (Frochot, 2005). In addition, current researches could not consider the human heterogeneity and the weights of each customer or developer. Therefore, the results obtained from conventional approaches are not sufficient to perform the development process in a comprehensive way.

In practice, certain linguistic variables validated intuitively for presenting the preferences of decision makers, may be more suitable for tackling processing the uncertainty (Kulak & Kahraman, 2005; Xu, 2009). The decision-making approach based on linguistic variables can accomplish the processes of calculating with words, which may avoid the risk of information loss (Xu, 2009). Some studies (Lin et al., 2010) employ a complete linguistic-based QFD to prioritize CRs, evaluate the relationship between CRs and solution schemes, and rank the solution schemes. However, all the customers and developers involved in QFD are treated equally, identical linguistic label set is used to express their preferences.

Since the customers or developers have their individual culture background, experience and understanding of the product being developed, they usually express their preferences with different linguistic label sets (Herrera, Herrera-Viedma, & Martínez, 2008). For example, some customers choose a 5-point linguistic set to represent the importance of CRs (e.g., 1-very unimportant, 2-unimportant, 3-fair, 4-important, 5-very important), while others select a 7-point linguistic set (e.g., 1-very unimportant, 2-unimportant, 3-medium unimportant, 4-fair, 5-medium important, 6-important and 7-very important).

In many of the aforementioned studies, linguistic variables from different label sets may be suitable for customers to make their assessments in the prioritizing process. In order to handle the multi-granular linguistic variables given by customers, the terms must be unified into a unique linguistic label set (Herrera, Herrera-Viedma, & Martínez, 2000). In this paper, a group multi-granular linguistic-based (GMGLB) approach is proposed to cope with multiple sources of linguistic variables expressed in different unbalanced linguistic label sets, which are computed directly to avoid the risk of information loss.

The rest of the paper is organized as follows. The unbalanced linguistic label sets and some operational laws are discussed in Section 2, the procedures of the GMGLB approach are presented in Section 3, and a case example is used to illustrate the proposed method in Section 4. The results from the proposed method are compared with other methods in Section 5. Finally, the key points of the study are summarized and concluded in Section 6.

2. Unbalanced linguistic label sets

There are many problems with product development in the real world, such as prioritizing the importance of CRs, and evaluating the functional relationship between CRs and ECs. Customers or developers usually express their preferences in quantitative linguistic terms, such as "important/strong", "fair" and "unimportant/weak". Generally, many approaches for constructing the HoQ are based on symmetrically and uniformly distributed linguistic label sets (Herrera et al., 2000; Xu, 2005). Xu (2009) demonstrates that the consensus degree of outputs obtained from the unbalanced linguistic label sets is clearly higher than that from the balanced linguistic label sets through a series of experiment. Therefore, unbalanced linguistic label sets are more suitable for determining the ranking of ECs. In this paper, an unbalanced linguistic set $S^{(t)}$, with zero as the center, is defined based on past research (Xu, 2005) as follows:

$$S^{(t)} = \left\{ s_\alpha^{(t)} \middle| \alpha = -(t-1), -\frac{2}{3}(t-2), \ldots, 0, \ldots, \frac{2}{3}(t-2), t-1 \right\} \quad (1)$$

where t is a positive integer, $s_\alpha^{(t)}$ denotes a possible value provided by customers, S is a finite and totally ordered discrete term set.

Definition 1. Let $s_\mu, s_\nu \in \boldsymbol{S}$ be two linguistic terms, and the deviation between s_μ and s_ν can be given as follows: