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A new hesitant fuzzy QFD approach: An application to computer workstation selection

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ABSTRACT

Computer workstation selection is a multiple criteria decision making problem that is generally based on vague linguistic assessments, which represent human judgments and their hesitancy. In this paper, a new fuzzy quality function deployment (QFD) approach is used to effectively determine the design requirements (DRs) of a computer workstation. Hesitant fuzzy linguistic term sets (HFLTS) are innovatively employed to capture the hesitancy of the experts in this approach. More precisely, the proposed new QFD approach is the first study that determines the importance of customer requirements (CRs), the relations between CRs and DRs and the correlations among DRs via HFLTS. Additionally, HFLTS based Analytic Hierarchy Process (AHP) and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) methods are utilized in the computational steps to select the best computer workstation. A real industrial application is carried out to validate the implementation of the proposed approach.

1. Introduction

A workstation is a customized computer that is designed for specific scientific or technical application. Increasing competition and technological innovation in the industry and business world in general brings about new developments in the workstation design. However, workstations are usually designed arbitrarily with little consideration to the specific needs and requirements of their users. Considering additional benefits of tailor-made workstations that are customized for specific uses and needs, a customer-driven approach in workstation design would benefit companies. Such an approach would not only capture customers' perspectives, but also raise the overall level of their satisfaction level. Quality function deployment (QFD) is a customer-driven tool that is widely used for product planning purposes. It can be beneficial to reach higher levels in customer satisfaction [1,2]. Good design requires consideration of design aspects that clients want and expect. To address this, QFD uses a matrix called House of Quality (HOQ) [3] that translates Customer Needs or Requirements (CRs) into engineering characteristics or Design Requirements (DRs). The HOQ is constructed with the importance weights of each of the CRs, as well as the correlation matrix among DRs and the relationship matrix between CRs and DRs [1–5].

The importance levels of CRs, functional relationships among CRs and DRs, and the assessments of alternatives based on DRs are difficult to express precisely. Although crisp data are needed to design workstations, experts usually prefer to provide their evaluations in linguistic terms. The fuzzy set theory lets these linguistic assessments be incorporated into numerical analyses. The ordinary fuzzy sets have been recently extended to Type 2 fuzzy sets, hesitant fuzzy sets, intuitionistic fuzzy sets, non-stationary fuzzy sets and fuzzy multisets [6]. Hesitant fuzzy sets (HFS), which are developed by Torra [7], allow more than one value for defining the membership value of an element, enabling an expert better express his/her assessment [8]. In this paper, we prefer to use hesitant linguistic term sets (HFLTS) in the development of a new fuzzy QFD approach since HFLTS enable the integration of various linguistic evaluations assigned by experts as an inclusive linguistic interval. HFLTS have been used in several papers in the literature [9–16].

Main features of the proposed hesitant fuzzy QFD approach are the use of HFLTS in the pairwise comparisons among CRs; the use of relations between CRs and DRs; the use of correlations among DRs, and the evaluation of alternatives. The weights of the CRs are determined by a hierarchical and pairwise comparison-based approach while the alternatives are ranked by using a hesitant fuzzy TOPSIS method. Besides, we propose a new approach taking the hesitant

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correlations among DRs into account in the HOQ operations. To the best of our knowledge, there is no QFD study based on hesitant fuzzy sets in the literature and this study is different from the other existing approaches since it considers the experts' hesitancies in each phase of the QFD approach.

The remainder of this paper is structured as the following; Section 2 presents basic concepts of QFD and a literature review of fuzzy QFD methodology. In Section 3, the main concepts of HFS and HFTLS are given. Section 4 gives the proposed decision making approach which is based on hesitant fuzzy QFD. In Section 5, a case study is provided to demonstrate the applicability of the proposed method. The last section concludes the paper and gives some perspectives.

2. Literature survey on fuzzy QFD

The overall methodological structure is based on the QFD technique, supported by a hesitant fuzzy set approach, where linguistic data are considered. In the following, first, basic QFD terminology on classical QFD is given. Then a literature review on fuzzy set extensions in QFD is given.

2.1. Quality function deployment (QFD)

QFD is a popular quality method that is developed in the 1960s and 1970s to address design quality challenges to meet better customer expectations [1,2]. QFD is a proven and comprehensive technique that is able to translate CRs into DRs by the so-called is HOQ [3]. The HOQ is the basic structure of QFD and includes the following integral components: the relationship matrix between CRs and DRs, CRs' importance weights, and the correlation matrix for DRs [1–5]. The well-known HOQ approach is depicted in Fig. 1.

The integral elements of the typical HOQ structure shown in Fig. 1 are briefly introduced below:

CRs: Customer requirements are also known as customer attributes, customer needs or demanded quality. The first step for constructing an HOQ is the identification, clarification and specification of customer needs. CRs represent the initial input for the HOQ and highlight those product specifications that should be paid attention to so that the "voice of the customer" is well understood.

DRs: Design requirements are also called product features, engineering attributes, technical attributes, engineering characteristics or substitute quality characteristics. These product requirements are associated with CRs.

CRs' analysis: Not all of CRs have the same level of importance for customers. In order to prioritize the identified CRs, a direct evaluation or different analytical techniques can be adopted.

Relationships matrix between CRs and DRs: The relationship matrix represents the extent to which each DR affects its associated CR. This matrix constitutes the body of the HOQ.

DRs' analysis: The results taken from the previous steps are used to compute the final importance degrees of DRs.

The HOQ is frequently discussed and applied in theoretical and practical literature, as it has the potential to significantly improve the accuracy of the preceding steps. HOQ is oriented towards design and is thus an important resource for designers. Furthermore, it is a tool that can summarize customers' feedback and translate it into a useful information format that can be easily understood and used by design teams.

Companies can enjoy various advantages when applying QFD, as it is customer-oriented, helps to combine large amount of verbal data, brings multifunctional teams together, improves the consensus processes, creates competitive advantage, decreases start-up and engineering costs borne during product development processes, and is usable across a wide range of processes and services in different sectors [1–5,17]. Thus, various business areas such as communication, software systems, transportation, electronics, education and research, manufacturing, services, IT and shipbuilding, aerospace, construction, packaging, textile industries and supply chain management make use of the QFD methodology [18–20].

In the next subsection, a literature review on fuzzy set extensions in QFD is given.

2.2. Fuzzy set extensions in QFD

The QFD method is a useful analysis tool that is widely used in product design and development. To deal with challenges related to uncertainty and imprecision in QFD, various researchers have developed many fuzzy QFD approaches by combining the fuzzy set theory with QFD. These approaches include conventional QFD computation methods using fuzzy variables [21,22], fuzzy outranking [23], entropy [24], incomplete fuzzy preference relations [25,26], multiple formatted fuzzy preference relations [27,28], fuzzy integral [29,30], fuzzy analytical network process [31,32], fuzzy multicriteria decision making (MCDM) [33,34], fuzzy goal programming [32,34], rough set based approach [35,36] and fuzzy expert systems [37], among others. Interested readers can refer to fuzzy QFD literature survey articles (e.g. [38]) for more detailed information.

Reviewed literature suggests that these fuzzy QFD approaches usually concentrate on obtaining the importance ranking of CRs and/or DRs. However, relatively a small number of papers investigate the selection process based on DRs. Our paper focuses on a DRs-based selection process.

Extended fuzzy set types include type-2 fuzzy sets, hesitant fuzzy sets, intuitionistic fuzzy sets, non-stationary fuzzy sets and fuzzy multisets. It is observed that the extended fuzzy sets are new topics and rarely used as modeling tools in QFD. In one of the first studies, Li [39] applied 2-tuple linguistic representation model under multi-granularity linguistic environment in the construction of HOQ. Ko [40] adopted a 2-tuple linguistic computational approach for constructing HOQ based failure modes and effects analysis, while Li et al. [41] handled software quality evaluation problem based on the geometric aggregation operators with hesitant fuzzy uncertain linguistic information. In another study, Li et al. [41] proposed an intuitionistic fuzzy set theory based QFD approach for the knowledge management system selection problem. In the proposed approach, the linguistic assessment data of HOQ are transformed into intuitionistic fuzzy numbers and the alternatives are prioritized and ranked with the intuitionistic TOPSIS method. Recently, Karsak and Dursun [42] employed a fusion of fuzzy information and 2-tuple linguistic representation model in the QFD to calculate the weights of supplier selection criteria and subsequently the ratings of suppliers.

3. Hesitant fuzzy linguistic term sets (HFLTS)

Hesitant fuzzy sets (HFSs) are the extensions of fuzzy sets which can solve the difficulties in determining the membership degree of an element [7]. It represents the hesitancy where there are possible values for membership and it is not clear which one is the right value.

Definition 1. A hesitant fuzzy set (HFS) on X, where X is a fixed set, can be defined as follows:

$$E = \left\{ < x, h_E(x) > | x\varepsilon X \right\} \quad (1)$$

where $h_E(x)$ denotes membership degrees of the element $x\varepsilon X$ to the set E and its values are in [0, 1].