This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

House of quality-based analysis of new service development using context free grammar evaluation-enhanced fuzzy hybrid modelling

HASAN DİNÇER[1], SERHAT YÜKSEL[1], LUIS MARTÍNEZ[2,*]
1 Istanbul Medipol University, Turkey
2 Universidad de Jaén, Spain

*Corresponding author: Luis Martínez (e-mail: martin@ujaen.es)

ABSTRACT The purpose of this study is to analyze new service development competencies based on house of quality (HoQ) in the healthcare industry by using a hybrid interval-valued intuitionistic decision-making approach with fuzzy linguistic information modelled by hesitant fuzzy linguistic term sets (HFLTSs) and linguistic 2-tuples. The novelty of the manuscript is to identify a list of criteria, dimensions, and alternatives for HoQ-based new service development used for the investment decisions in healthcare industry. Thus, a hybrid model with HFLTSs has been proposed, considering 2-tuple linguistic information, Interval-Valued Intuitionistic Fuzzy Sets (IVIFSs) and a defuzzification process with an attitudinal expected score function. Hence, a DEMATEL extension dealing with HFLTSs, linguistic 2-tuple and IVIFS has been developed and used to weigh the criteria and dimensions of customer needs. Similarly, a TOPSIS extension dealing with the same type of information is introduced and applied in order to rank the technical requirements, the so-called "new service development competencies in healthcare industry". The results show which are the most and least important dimensions for patients' needs, and also point out which dimensions can be applied more effectively to satisfy the needs of service demanders. The findings obtained could be generalized to a country level analysis, and other extensions of multi-criteria decision-making methods could be applied to future studies.

INDEX TERMS Hesitant fuzzy linguistic term sets; Linguistic 2-tuples; Interval-valued intuitionistic fuzzy sets; DEMATEL; New Service Development; Healthcare industry

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

I. INTRODUCTION

Quality improvement is the most prominent issue in the service industry. In particular, globalization has led to new service development activities as a result of competitive market activities. Technological developments have increased the flow of knowledge globally and has helped obtain the market conditions and specifications easily and comparatively [1]. Therefore, the quality management and development of innovative strategies form part of the new trends of global trade and market environment [2]. With this is mind, companies are trying to enhance customer satisfaction by developing strategies to improve quality management.

All parties of market providers, including producers, suppliers, and dealers should strictly comply with the expectations of customers in order to survive in the global competitive market. Accordingly, HoQ was introduced in the 1970s and applied successfully by Japanese producers to develop the quality functions [3]. This technique illustrates the needs of a target market, and of including wholesale and/or retail customers systematically by matching them to a set of technical facilities. Thus, it is possible to figure out the importance degrees of customer expectations in terms of technical requirements [4]. Similarly, this technique could be also applied in the healthcare industry in order to try to understand customer and patient needs more accurately, in the context of the technical requirements of healthcare services [5,6].

The exact factors of customer/patient needs should be defined by understanding the market trends and expectations. To do so, one of the most important phenomena is defining customer expectations in financial terms [7]. Customers generally expect service prices to be fair. Potential customers and patients should be able to afford the pricing policies of healthcare services [8,9]. Furthermore, if competitive pricing policies are used as strategic tools for the health industry, they could help companies become market leaders [10,11]. Additionally, some patients also search for payment options, such as instalment sales and delays with flexible payments. Therefore, the producers and sales-including service providers in the healthcare industry should attempt to satisfy these types of customer expectations in financial services in order to fulfil the market gaps [12,13].

Additionally, customers not only call for the functionality of the services rendered, but they also expect financial facilities. In the health industry, patients and demanders of health services want the health industry to be convenient for all kinds of market needs and expectations. Accordingly, patients frequently request ease of access to the healthcare services [14]. For this purpose, alternative distribution channels such as telehealth and e-health could be diversified to provide multi-channel services of the healthcare industry [15]. Moreover, improving the reliability of healthcare services could lead to greater patient loyalty in the long term [16]. Thus, it is possible to achieve customer retention by increasing cross-selling possibilities in the healthcare industry. Similarly, customer support is also expected by the demander of healthcare services in order to be able to reach to continuous healthcare services [17].

Another important issue arising from customer expectations in the healthcare industry is making sufficient physical facilities available in order to provide customer satisfaction in medical services. Competitive health services force health companies to be more generous than conventional healthcare suppliers. For instance, hospitals and medical companies could operate their activities with flexible working hours. Thus, service demanders of the healthcare industry could get medical assistance in a wide range of working times [18]. Location is another physical condition that is the important for the patients [19]. Generally, the customers expect to obtain services in a central place, and this could be made possible by increasing the branches of hospitals and the number of medical services effectively [20]. Finally, hygiene is one of the most important factors in the physical conditions demanded/expected by patients and other demanders of healthcare services. This factor is standardized by regulations, but the hygiene level of medical services could be increased according to the services customers expect to receive from the medical companies [21].

However, suppliers of healthcare services should operate their activities with technical requirements that are suited to customer needs in the health industry. Within this framework, medical companies and other suppliers in the healthcare industry should focus on the competitive technical requirements by considering the innovation and new service development competencies to improve their service quality. In particular, organizational capacity should be managed more effectively by the best providers of healthcare services [22].

Technological background has also been considered for the incremental improvement of service quality. In particular, healthcare companies and hospitals regularly invest in technological devices and equipment entitled non-current assets. Hence, medical companies can operate their activities more effectively with high-technological devices, meeting patient expectations [23]. By providing this functionality, medical services can offer more flexibility according to the needs of the healthcare industry [24]. Operational convenience is another technical requirement of the healthcare industry. Thus, technical standards are obtained globally with operational appropriateness and therefore the operational mistakes of the healthcare industry are reduced [25]. Furthermore, cost management in the healthcare industry is one of the most efficient technical factors that can help provide competitive healthcare services to the patients. As such, pricing policies could be redesigned with efficient service management [26].

The use of multi-criteria decision-making (MCDM) models for the HoQ technique is quite limited in the literature, and

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

generally, conventional decision-making models have been applied to analyse the quality improvement of the service industry [27, 28]. In particular, new service development and innovation are considered to be novel issues for the application of HoQ. HoQ, however can also consider several sources of information for complex decision-making issues, such as context-free grammar evaluations and the continuous presentation of linguistic evaluations for both customer and technical factors. Accordingly, HFLTSs, 2-tuple linguistic information, and IVIFSs could provide more comprehensive and coherent results in the complex decision-making problems of quality studies. Additionally, the decision makers' attitudinal character can be used to check the consistency of the defuzzified values. So, the attitudinal expected score function could be applied to provide comprehensive results and the sensitivity analysis. Moreover, DEMATEL reveals the mutual relationships and influences between criteria. TOPSIS is a unique method used to rank alternatives by ordering preferences according to the distance from the ideal solution. Hence, this paper aims at providing a novel perspective by combining a hybrid decision making approach with the proposed criteria and dimensions of patient needs and the technical requirements of new services in healthcare industry. Accordingly, hesitant fuzzy linguistic based with 2-tuple and IVIF DEMATEL and TOPSIS models are defined and used in the house of quality-based evaluation of new service development competencies in healthcare investments.

To achieve the main goal of this proposal, several novelties are introduced throughout this paper as follows:

- Construct a theoretical background of new service development by using an HoQ approach in the health industry.
- Propose a hybrid decision making model with the extensions of DEMATEL and TOPSIS based on HFLTSs, 2-tuple linguistic information, and IVIFSs.
- Integrate the attitudinal expected score function to compute the results of the local and global criteria and dimension weights and facilitate a sensitivity analysis.

Section 2 indicates the literature evaluation of HoQ for production and service industries as well as healthcare services in detail. The following section explains the methodology with the extended methods of DEMATEL and TOPSIS. Section 4 gives information on its application in the healthcare industry. In the last section, the paper is discussed and concluded for future research.

II. LITERATURE REVIEW

HoQ is one of the well-known techniques in the research areas of quality improvement. It has been frequently studied in several areas of the production industry, such as technological development [29,30], organizational factors [31], design [32, 33], environmental issues, and efficiency [34]. However, in the literature, limited studies using the HoQ are available in the field of service industries. Essential HoQ topics studied in the service industry are detailed below.

The most studied HoQ topic in the service industry is logistic and transportation service. Bottani and Rizzi [35] highlight the strategic importance of quality improvement for logistic industry and construct a fuzzy-based houses of quality approach to analyse the efficiency of logistics process. Outcomes are generalized for customer satisfaction in logistic industry. Vazifehdan and Darestani [27] present a comprehensive model for ranking the outsourced green logistics based on HoQ factors using fuzzy ANP and DEMATEL. It is understood that green political decision-making is the most influential item, while quality should be redesigned in order to achieve sustainable business operations with high customer satisfaction. Ho et al. [28] imply the strategic logistic outsourcing by using HoQ. Fuzzy AHP-based HoQ is used to evaluate the optimal third-party logistic service providers together with the needs of stakeholders in Hong Kong. The proposed method is employed along with the outsourcing and third-party logistics services in order to obtain the optimal business strategies. Wang [36] assesses the service quality of the Chinese cargo sector, using the HoQ to figure out the competitive factors of the airline industry. The findings show/suggest that the quality of the technology used could increase both industry performance and customer expectations. Pandey [37] explores the strategic design factors of low-cost airlines using quality function deployment by integrating an HoQ analysis with fuzzy sets. The results show that the strategic factors could be generated by considering customer-oriented factors.

Another important research area of HoQ-based service analysis is the supply chain and management. Büyüközkan and Berkol [38] integrate analytic network processes and goal programming with HoQ to design a sustainable supply chain management. For this purpose, several economic, social, and environmental requirements are defined in order to provide service networks to suppliers, manufacturers, and customers. The results are discussed to determine the most effective design requirements of the sustainable supply chain management. Na et al. [39] measure the amount/level of power supply service quality that meets both customer satisfaction and service requirements with HoQ. The proposed model is recommended for the managerial decision-making process of service items. Santos et al. [40] propose a HoQ-based multi-criteria evaluation model for the environmental service providers of waste generator companies, including recycling, recovery, transportation, and disposal facilities. It is concluded that these applications could be applied in a broader sense to potential relationships shared between the environmental factors.

Additionally, internet services and innovation management are also studied with HoQ. Zuo et al. [41] investigate the commercial e-services quality requirements for businesses using the Kano model. The requirements and specifications of quality are measured with the HoQ technique. It is

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

concluded that the HoQ-based measurement could improve the quality of e-commerce services and provide effective implications for company policies. Min and Kim [42] define a QFD planning model for the design requirements of internet services with HoQ dimensions. It is proposed that high-speed internet service is required to improve customer loyalty in project selection. Lin et al. [43] propose an HoQ model with fuzzy linguistic preferences, including external and internal service management factors, to address the service innovation processes and tourist satisfaction. The experimental results demonstrate that effective directions are required for service innovations and in order to gain competitive advantage in the hotel industry.

Some studies in the field of modularization and retailing serve as a guide for improving service quality. Geum et al. [44] use a modified HoQ approach to compare the manufacturing and modularization of services. The relationship between module drivers and decomposed service factors are employed with the strategic modularability matrix in the HoQ structure. The results show that the service-specific module drivers modularize services and analyse the interrelations among the factors. Trappey et al. [45] employ a computerized HoQ approach for retail services in order to design competitive strategies in the market environment. It is recommended that managerial objectives be rethought by implementing, as an object-oriented quality system prototype, customer-driven strategic plans. Park et al. [46] have promoted the Korean food industry to international customers using the HoQ technique. Food services are introduced with the requirements of food services, and the expectations of international customers and the relative importance of the selected factors are defined to develop the most effective food service strategies.

However, HoQ is seldom studied in health economics and management. Bas [5] investigates HoQ with an integrated model using capital budgeting for occupational health and safety as a system thinking approach. In this study, interrelationships between several factors, including tasks and hazards, hazards and events, events and preventive measures are measured using? the quality function deployment stages. Some policies are generated for the continuous development of occupational health and safety in the construction industry. On the other hand, Wey and Chiu [47] assess the effects of pedestrian environment to analyse non-motorized transportation modes that lead to emission reduction and improve public health. Analysis results show that transit-oriented planning could positively affect traffic speed and pedestrian accessibility in the context of the development of public health. Additionally, Kuo et al. [6] study outpatient services to establish an age-friendly healthcare system in Taiwan. For this purpose, HoQ is used to measure the outpatient services with Kano's model and an analytic network process technique. The results show that the analysis with HoQ could increase the quality of medical care together with cost efficiency. Zadry et al. [48] identify the design requirements for the ergonomic issues when quality function deployment and emergency medical services are applied in order to integrate customer needs into the engineering requirements. The findings are illustrated so as to focus on the design priorities of the provided services.

As seen in the literature review, customer satisfaction plays an essential role in the healthcare industry. However, it is also understood that hospitals should make necessary technological developments in order to meet customer expectations. Hence, this paper will provide several novel contributions to the health economics and management literature. Firstly, based on the HoQ approach, both customer expectations and technical requirements are used. This will help us to understand which factors the hospitals should be developed with respect to the technical aspects in order to meet customer expectations. Moreover, while providing a novel hybrid decision making model based on 2-tuple linguistic information and IVIFSs, as well as HoQ-based evaluation of new service development in health investments, the methodology seems to become very different to those presented in similar studies in the literature.

III. BACKGROUND

In complex decision-making problems, conventional methods have been modified and extended to obtain more accurate and coherent results. Earlier studies of complex problems were introduced by Zadeh in the 1960s by using fuzzy sets [49], and studies have since used several extensions of fuzzy sets to provide comprehensive outcomes [50]. Currently, some decision-making problems are still waiting to learn from the integrated decision-making models. These problems could be referred to as consensus difficulties in linguistic evaluations made by the decision makers [51] and the need for intermediate values as well as computing with words in/to create/construct linguistic information [52].

To solve this type of complex problem, hesitant fuzzy linguistic term sets could be used to create better knowledge and preference modelling by using context-free grammar. This would facilitate the elicitation of complex linguistic evaluations and make it more similar to a human being's cognitive process, including mental and reasoning processes, which would enable the development of linguistic decision making with computing with words [53]. Accordingly, the 2-tuple linguistic model was introduced at the beginning of 2000s by Herrera and Martinez [52] and it has successfully contributed to the methodological soundness in the research areas of computing with words and linguistic decision and modelling.

However, intuitionistic fuzzy sets are a well-known extension of fuzzy sets that have, to date, once again become a hot topic in the decision-making area [54, 55]. They have several advantages, for example, they provide the extreme limits for the belongingness and non-belongingness elements and construct the vague sets more accurately [56]. Atanassov

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

[57] introduced the intuitionistic sets in the 1980s as a generalized form of fuzzy sets and developed IVIFSs [58,59]. The earlier extensions of intuitionistic fuzzy sets were studied by Gau and Buehrer [60] and Bustince and Burillo [61] to provide close similarities to the intuitionistic sets and MCDM methods.

In this study, 2-tuple linguistic information and HFLTs are integrated into? the extension of IVIFSs. The essentials of 2-tuple linguistic information, HFLTs and IVIFSs are illustrated respectively as follows:

A. LINGUISTIC 2-TUPLE MODEL

The 2-tuple fuzzy linguistic representation model is a symbolic based method [62] and takes the concept of Symbolic Translation as the basis of its representation.

Definition 1 [52]. *The Symbolic Translation of a linguistic term* $s_i \in S = \{s_0, \ldots, s_g\}$ *is a numerical value assessed in* [-0.5, 0.5) *that supports the "difference of information" between an amount of information* $\beta \in [0, g]$ *and the closest value in* $\{0, \ldots, g\}$ *that indicates the index of the closest linguistic term in S* (s_i), *where* $[0, g]$ *is the interval of granularity of S.*

From this concept, a new linguistic representation model is developed that represents linguistic information by means of 2-tuples (si, αi), si ∈S and αi∈[-0.5, 0.5]. It defines the two different functions of linguistic 2-tuples and numerical values as:

Definition 2 [52]. *Let* $S = \{s_0, \ldots, s_g\}$ *be a linguistic term set and* $\beta \in [0, g]$ *a value supporting the result of a symbolic aggregation operation. Then the 2-tuple that expresses the equivalent information to* β *is obtained with the following function:*

$$\Delta: [0, g] \to S \times (-0.5, .0.5) \qquad (1)$$
$$\boldsymbol{\Delta(\beta) = (s_i, \alpha)}, \textit{ with}$$
$$\begin{cases} s_i & i = round(\beta) \\ \alpha = \beta - i & \alpha \in [-0.5,0,5) \end{cases}$$

where round(·) is the usual round operation, s_i has the closest index label to "β" and "α" is the value of the symbolic translation.

Proposition 1 [52]. *Let* $S = \{s_0, \ldots, s_g\}$ *be a linguistic term set and* (s_i, α_i) *be a linguistic 2-tuple. There is always a* Δ^{-1} *function, such that, from a 2-tuple it returns its equivalent numerical value* $\beta \in [0, g]$ *in the interval of granularity of S.*

Proof. If it is trivial, we consider the following function: $\Delta^{-1}: S \times [-0,5,0.5) \to [0, g], \quad \Delta^{-1}(s_i, \alpha) = i + \alpha = \beta.$

This model has a computational technique based on the 2-tuples and multiple operators as can be seen in [53]. The results with 2-tuple linguistic information are presented as (S_i, α) and $\alpha_i \in [-.5, .5)$. They are illustrated as seen in Figure 1 [52, 63, 64].

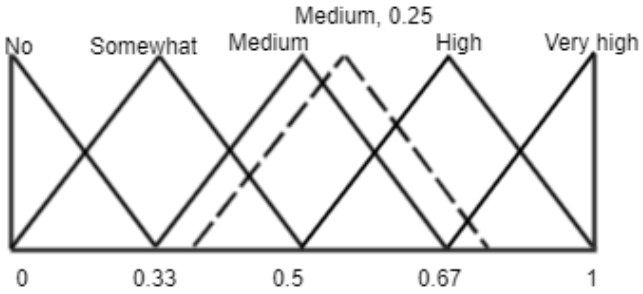


FIGURE 1. 2-tuple linguistic information and sets

B. HESITANT FUZZY LINGUISTIC TERM SETS

In [65], the concept of HFLTS was introduced.

Definition 3 [65]. Let $S = \{s_0, \cdots, s_\tau\}$ be a linguistic term set. An HFLTS (H_S) is defined as follows

$$H_S = \{s_i, s_{i+1}, \cdots, s_j\}, s_k \in S, k \in \{i, \cdots, j\} \qquad (2)$$

The use of context-free grammars $G_H = (V_N, V_T, I, P)$ was introduced to generate comparative linguistic expressions. An illustrative context free grammar used to build such expressions was provided in [65] as,

$$V_N = \begin{Bmatrix} \langle primary\ term \rangle, \langle composite\ term \rangle, \\ \langle unary\ term \rangle, \langle binary\ term \rangle, \langle conjunction \rangle \end{Bmatrix},$$
$$V_T = \begin{Bmatrix} lower\ than, greater\ than, at\ least, \\ at\ most, between, and, S_0, S_1, \ldots, S_t \end{Bmatrix},$$
$$I \in V_N,$$
$$P = \{I ::= \langle primary\ term \rangle | \langle composite\ term \rangle,$$
$$\langle composite\ term \rangle ::= \langle composite\ term \rangle$$
$$\langle primary\ term \rangle$$
$$\left| \begin{matrix} \langle binary\ relation \rangle \langle primary\ term \rangle \\ \langle conjunction \rangle \langle primary\ term \rangle, \end{matrix} \right.$$
$$\langle primary\ term \rangle ::= S_0 | S_1 | \ldots | S_t,$$
$$\langle unary\ relation \rangle$$
$$::= lower\ than | greater\ than | at\ least | at\ most,$$
$$\langle binary\ relation \rangle ::= between,$$
$$\langle conjunction \rangle ::= and\}.$$

Such expressions can be transformed into HFLTS by means of the transformation function given below.

Definition 4 [65]. Let $S = \{s_0, \cdots, s_\tau\}$ be a linguistic term set, the transformation function E_{G_H} converts the comparative linguistic expressions $ll \in S_{ll}$ generated by the context-free grammar G_H into HFLTSs, H_S.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

$$E_{G_H}: S_{ll} \rightarrow H_s \quad (3)$$

S_{ll} is a domain. The comparative linguistic expressions ll are obtained in a similar way to the fuzzy linguistic variables, using fuzzy membership functions (trapezoidal ones) to compute their fuzzy envelops [66, 67]:

$$F(H_s) = T(a, b, c, d) \quad (4)$$

C. IVIFSs

IVIFSs are a generation of fuzzy set and define the membership and non-membership degrees of elements with extreme values. Therefore, it is possible to obtain more precise results with complex decision-making problems [68]. Intuitionistic fuzzy set I on U is illustrated as in equation (5) [69].

$$I = \{\langle \vartheta, \mu_I(\vartheta), n_I(\vartheta)\rangle / \vartheta \epsilon U\} \quad (5)$$

Where the $\mu_I(\vartheta): U \rightarrow [0,1]$ and $n_I(\vartheta): U \rightarrow [0,1]$ are the membership and non-membership degrees, defined as $0 \leq \mu_I(\vartheta) + n_I(\vartheta) \leq 1$.

$\mu_I(\vartheta)$ and $n_I(\vartheta)$ are intervals which are also the degrees of belongingness and non-belongingness of ϑ , respectively.

$\vartheta \epsilon U$ is for each interval, and $\mu_{IU}(\vartheta)$ is the upper value and $\mu_{IL}(\vartheta)$ is the lower value of $\mu_I(\vartheta)$ whereas $n_{IU}(\vartheta)$ is the upper value and $n_{IL}(\vartheta)$ is the lower value of $n_I(\vartheta)$ that are given as $\mu_{IL}(\vartheta), \mu_{IU}(\vartheta), n_{IL}(\vartheta), n_{IU}(\vartheta)$. Intuitionistic fuzzy set I on U is presented with the equation (6).

$$I = \{\vartheta, [\mu_{IL}(\vartheta), \mu_{IU}(\vartheta)], [n_{IL}(\vartheta), n_{IU}(\vartheta)] / \vartheta \epsilon U\} \quad (6)$$

Where

$$0 \leq \mu_{IU}(\vartheta) + n_{IU}(\vartheta) \leq 1 \qquad \mu_{IL}(\vartheta) \geq 0, \qquad n_{IL}(\vartheta) \geq 0 \quad (7)$$

Unknown degree of an intuitionistic fuzzy interval of $\vartheta \epsilon U$ in I is defined as follows

$$\tau_I(\vartheta) = 1 - \mu_I(\vartheta) - n_I(\vartheta) \quad (8)$$

The elements from the IVIF set (I) are given as

$$I = ([a, b], [c, d]) \quad (9)$$

where a, b, c, d are $\mu_{IL}(\vartheta), \mu_{IU}(\vartheta), n_{IL}(\vartheta), n_{IU}(\vartheta)$ respectively.

IV. ANALYSIS FOR HEALTHCARE INVESTMENTS WITH FUZZY LINGUISTIC INFORMATION AND IVIFSs

In this section, a novel hybrid multi-criteria decision-making model is proposed to analyze the new service development process in the healthcare industry and investments by using HFLTSs, 2-tuple fuzzy linguistic information and IVIFSs properly. To this end, the house of quality-based decision matrix is defined by meeting the customer expectations and technical requirements of healthcare investments. The analysis flowchart and the details of novel extensions for the hybrid model are illustrated accordingly in the following subsections.

HYBRID MODEL BASED ON IVIFSs

This study aims to evaluate new service development process for healthcare investments. Therefore, we aim to understand which factors in the area of technical aspects should be of more importance to hospitals in order to meet customer expectations. HoQ approach is taken into account as it considers both technical requirements and customer satisfaction. Moreover, in this study, a hybrid multi-criteria decision-making model with HFLTSs, 2-tuple linguistic information and IVIFSs is proposed to determine the weights of the criteria and the dimensions of customer requirements, and to rank the alternatives of technical requirements for the new service development competencies of healthcare investments. Accordingly, this hybrid method contributes to the literature of multi-criteria decision-making by using the extensions of DEMATEL and TOPSIS methods, and including the HFLTs, 2-tuple linguistic information and IVIFSs. Thus, this paper aims to provide more comprehensive and accurate results using the modified technique on? the house of quality-based new service development competencies in healthcare investments. The proposed flowchart is illustrated in Figure 2.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

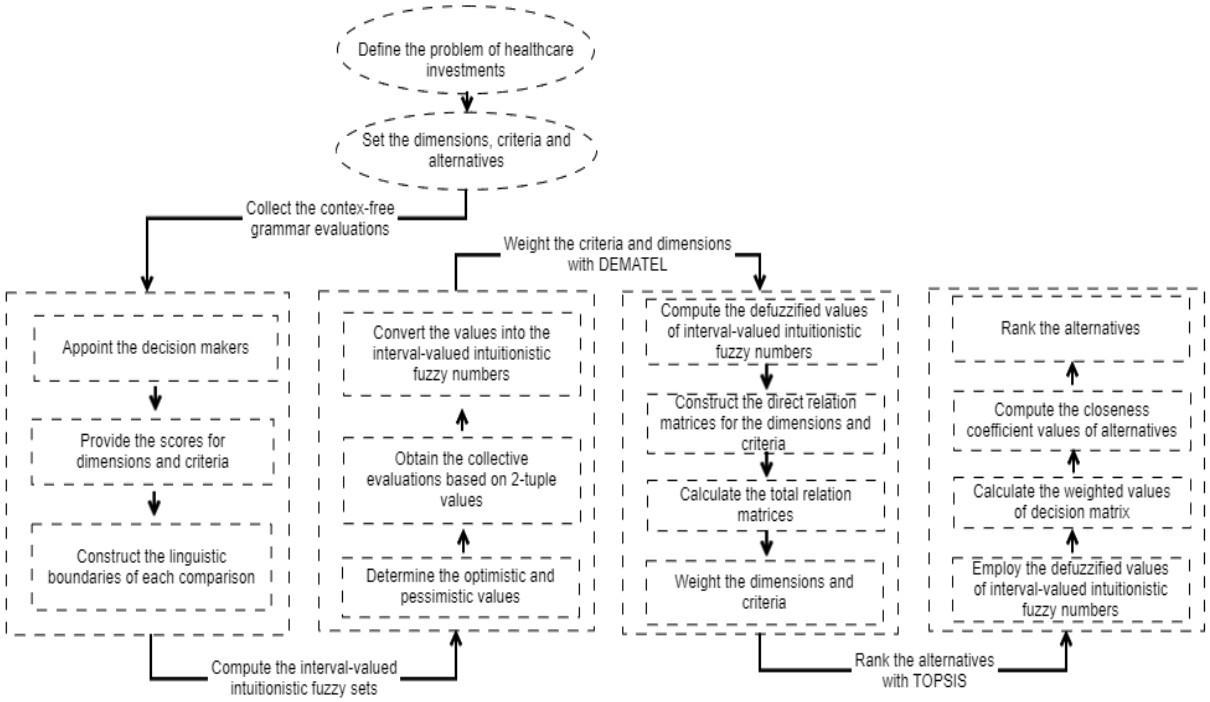


FIGURE 2. **Flowchart of proposed model**

The steps of the proposed hybrid decision making model are summarized as follows

Step 1. Define the MCDM problem of healthcare investments based on house of quality.

Step 2. Identify customer needs and technical requirements for new service development in the healthcare industry with HoQ.

Step 3. Appoint those decision makers that are academicians and experts in the field of the healthcare industry.

Step 4. Collect evaluations from the experts.

Step 5. Set the boundaries of linguistic evaluations for the collective evaluations with 2-tuple information.

Step 6. Generate the IVIFSs by considering the optimistic and pessimistic values of customer expectation factors for the healthcare industry.

Step 7. Compute the defuzzified values with accuracy functions for criteria, dimensions, and alternatives for the HoQ-based evaluation of healthcare investments.

Step 8. Construct direct relation matrices.

Step 9. Compute total relation matrices.

Step 10. Apply the attitudinal expected score function to compute the local and global weights of criteria and the decision matrix.

Step 11. Define the decision matrix for the technical requirement alternatives.

Step 12. Compute the weighted decision matrix by using the global weights of customer expectations.

Step 13. Calculate the values of D+, D- and the closeness coefficient for the alternatives of technical requirement in healthcare investments.

Step 14. Measure the HoQ-based new service development competencies for healthcare investments.

A more detailed description of the extensions of the DEMATEL and TOPSIS methods proposed in the previous model are provided in the following subsections.

A NOVEL EXTENSION OF DEMATEL DEALING WITH HFTLSS, IVIF SETS AND LINGUISTIC 2-TUPLES

DEMATEL is the abbreviation of Decision-Making Trial and Evaluation Laboratory and was introduced by the Geneva Research Centre in the 1970s to analyzing the impact and relationship degrees of criteria in a comprehensive manner [70]. This method is one of the most popular decision-making techniques as it measures the mutual relationship directions and weights among the criteria [71].

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

In the literature, there are several fuzzy extensions of DEMATEL found in the managerial [72-75] and economic issues [76-79], where the triangular and trapezoidal fuzzy sets are used to measure the weights of those factors found in a complex decision-making environment.

However, use of IVIFSs is extremely limited in the current literature concerning DEMATEL [80]. IVIF sets with 2-tuple linguistic information contribute to the DEMATEL literature as the expert's choices can be evaluated more accurately by using linguistic fuzzy information and computing with words simultaneously at the boundaries of optimistic and pessimistic evaluations. The computation procedures of DEMATEL based on IVIFSs and 2-tuple linguistic information are summarized in the following steps:

Step 1. Collect the decision makers' preferences that were elicited by complex expressions based on HFLTSs assessed in $S = \{S_0, S_1, \ldots, S_t\}$. These HFTLSs are transformed into fuzzy membership functions by computing their envelopes F(Hs) (see eq. (4)).

Step 2. Construct the interval-valued intuitionistic fuzzy sets: The optimistic and pessimistic values are calculated. After that, optimistic and pessimistic values are defined as the degrees of belongingness $\mu_I(\vartheta)$ and non-belongingness $n_I(\vartheta)$ of ϑ respectively. The extreme values of optimistic and pessimistic evaluations are given in the form of $\mu_{IL}(\vartheta), \mu_{IU}(\vartheta)$, $n_{IL}(\vartheta), n_{IU}(\vartheta)$. Obtained values are presented in the interval-valued intuitionistic fuzzy sets I as

$$\tilde{Z}_{ij} = \left((a_{ij}, b_{ij}), (c_{ij}, d_{ij})\right) \quad (10)$$

Where, $\tilde{Z}_{ij}$ is the value of direct relation matrix based on IVIFSs. a_{ij}, b_{ij}, c_{ij}, d_{ij} are the relation degrees of criteria and dimensions in the IVIFSs. In this context, a_{ij} and b_{ij} give the extreme values of the belongingness degree. The terms c_{ij} and d_{ij} are the lower and upper values of non-belongingness for the criteria and dimensions.

A defuzzification process is applied by computing the score function of IVIFSs. There are several methods that can be employed to obtain the defuzzified values of the relation and decision matrices. However, the additional parameters could add to the score function to be able to provide more comprehensive results. For instance, the specifications of the experts can be also considered in the defuzzification process. Accordingly, attitudinal expected score function gives comprehensive information with the decision makers' attitudinal character in order to check the consistency of the evaluations and apply the sensitivity analysis [81]. This score function is computed by Equation (11) and is used as a defuzzification process:

$$A(i) = \frac{(1-\lambda)\times(a_{ij}-c_{ij})+\lambda\times(b_{ij}-d_{ij})+1}{2} \quad (11)$$

where $A(i)$is the attitudinal expected score degree of IVIFSs and $A(i) \in [0,1]$. λ is the parameter that defines the decision makers' attitudinal character.

The direct relation matrix is illustrated with the formula (12).

$$A_k = \begin{bmatrix} 0 & \cdots & a_{1nk} \\ \vdots & \ddots & \vdots \\ a_{n1k} & \cdots & 0 \end{bmatrix} \quad (12)$$

Step 3. Calculate the normalized values of the direct relation matrix: the normalized matrix is defined by the Equation (13)

$$B = [b_{ij}]_{nxn} = \frac{A}{max \sum_{j=1}^{n} a_{ij}} \quad (13)$$

Where b_{ij} is between 0 and 1.

Step 4. Compute the total relation matrix: the total relation matrix C is defined as

$$C = [c_{ij}]_{nxn} = B(I-B)^{-1} \quad (14)$$

Where C presents the total relation matrix whereas I defines the identity matrix.

Step 5. Calculate the sums of all vector rows and columns: the values of D and E are provided by summing all vector rows and columns of the total matrix, respectively. The values of D+E define the prominence degrees while the values of D-E give the impact-relation directions with the Equations (15) and (16).

$$D = [d_{ij}]_{nx1} = \left[\sum_{j=1}^{n} c_{ij}{}_{ij}\right]_{nx1} \quad (15)$$

$$E = [e_{ij}]_{1xn} = \left[\sum_{j=1}^{n} c_{ij}{}_{ij}\right]_{1xn} \quad (16)$$

A NOVEL EXTENSION OF TOPSIS DEALING WITH HFLTSS, IVIF SETS AND LINGUISTIC 2-TUPLES

The technique for order performance by similarity to ideal solution (TOPSIS) is one of the most well-known MCDM methods used to rank alternatives in terms of negative and positive ideal solutions. This method was generated by Yoon and Hwang in the 1980s and the applicability of this method has since been improved by computing the distances from the ideal solution, the shortest distance to the positive solution and the longest distance to the negative solution [82, 83]. In the TOPSIS literature, there are immense studies in the different areas of economics and management, such as supplier selection [84, 85], firm evaluation [86], location selection [87], economy development [88]. Several extensions of TOPSIS are also introduced to provide more comprehensive results in the literature. In this study, by utilizing the advantages of computing with words and intervals of fuzzy linguistic term sets, we aim to propose an extension of TOPSIS based on 2-tuple linguistic information and IVIFSs. The procedures of extended TOPSIS are given in the following steps:

Step 1. Collect the HFLTS based evaluations of decision makers whose extreme values are defined into the interval-valued intuitionistic fuzzy sets in order to construct the IVIF decision matrix. Similarly, the first two procedures of the

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

extended DEMATEL are applied to compute the overall values of the decision matrix.

Step 2. Construct the decision matrix: the results of accuracy function are used to obtain the defuzzified values of the 2-tuple IVIF decision matrix with the formulas (17) and (18).

$$\mathrm{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} \mathrm{C1} & \mathrm{C2} & \mathrm{C3} & \ldots & & \mathrm{Cn} \end{array} \\ \begin{bmatrix} h_{11} & h_{12} & h_{13} & & \cdots & h_{1n} \\ h_{21} & h_{22} & h_{23} & & \cdots & h_{2n} \\ h_{31} & h_{32} & h_{33} & & \cdots & h_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ h_{m1} & h_{m2} & h_{m3} & & \cdots & h_{mn} \end{bmatrix} \end{array} \tag{17}$$

$$h_{ij} = \frac{1}{k}\left[\sum_{e=1}^{n} h_{ij}{}^{e}\right] \tag{18}$$

where A_1, A_2, . . ., A_m defines the alternatives as C_1, C_2, . . ., and C_n gives information on the criteria. However, the term h_{ij} is the evaluation of the results of alternatives on criteria, obtained using accuracy function. i=1,2,3,…,m. and k indicates the expert numbers. Averaged values of the decision makers are employed to define the decision matrix.

Step 3. Weight the decision matrix: the decision matrix is weighted using the Equations (19) and (20).

$$A^{+} = max(v_1, v_2, v_3, \ldots v_n) \tag{19}$$

$$A^{-} = min(v_1, v_2, v_3, \ldots v_n) \tag{20}$$

where (A^{+}) represents the positive values and (A^{-}) the negative values for the ideal solutions. Also, v_{ij} illustrates the weighting results of the decision matrix.

Step 4. Calculate the values of the closeness coefficient: the values of D+ and D- are computed to measure the values of the closeness coefficient (CC_i) with the formulas (21)-(23).

$$D_i{}^{+} = \sqrt{\sum_{i=1}^{m} (v_i - A_i{}^{+})^2} \tag{21}$$

$$D_i{}^{-} = \sqrt{\sum_{i=1}^{m} (v_i - A_i{}^{-})^2} \tag{22}$$

$$CC_i = \frac{D_i^{-}}{D_i^{+} + D_i^{-}} \tag{23}$$

For the list of the performance of alternatives, the values of CC_i are ranked in descending order.

V. ANALYSIS

This study aims at identifying the more significant criteria in order to/to help increase customer satisfaction. Additionally, this paper also attempts to understand which factors companies should develop in respect to technological requirements in order to be able to achieve this objective. A hybrid decision making approach based on 2-tuple linguistic information and IVIFSs has been proposed to analyse the HoQ-based new service development competencies in the healthcare industry. To this end, the healthcare industry MCDM problem was defined and the factors of HoQ were adapted to the new service development competencies in the healthcare industry. After that, the context-free linguistic evaluations were collected from the decision makers, who are academicians and experts in the field of healthcare services. By obtaining values for the criteria, dimensions, and alternatives, the extended DEMATEL and TOPSIS methods are applied consecutively to the house of quality-based evaluations of new service development competencies in healthcare industry. The analysis results are given in the following stages.

Stage 1. Define the MCDM problem

MCDM problem is defined with customer expectations and technical requirements of new service developments in the healthcare industry. Figure 3 presents the healthcare industry decision matrix with the HoQ factors.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

			Technical Requirements								
			Organizational capacity	Technological infrastructure		Functionality		Operational convenience			Cost management
			C1 C2.....C(n-1) Cn								
Customer Expectations	Price fairness	C1	C1,C1	C1,C2	...	...	...	…	...	...	C1,Cn
		C2	...	...	...	...	...	.. .	...	...	...
	Competitive charges	.	.	.	.	.	.	.	.	.	.
		.	.	.	.	.	.	.	.	.	.
	Payment facilities	.	.	.	.	.	.	.	.	.	.
	Ease of access	.	.	.	.	.	.	.	.	.	.
		.	.	.	.	.	.	.	.	.	.
	Reliability	.	.	.	.	.	.	.	.	.	.
	Customer support	.	.	.	.	.	.	.	.	.	.
	Working hours	.	.	.	.	.	.	.	.	.	.
	Hygiene	.	C(n-1),C1	...	...	...	...	.. .	...	...	C(n-1),Cn
	Location	C(n-1) Cn	Cn,C1	....	...	...	...	.. .	...	...	Cn,Cn

FIGURE 3. House of Quality-based decision matrix

The criteria and dimensions of customer expectations and the technical requirements of new service development competencies for the healthcare industry are determined using the supported literature. Tables 1 and 2 show 3 dimensions and 9 criteria of customer expectations as well as 5 technical requirements for the HoQ-based evaluation in the healthcare industry.

TABLE 1. Customer expectations for healthcare industry

Dimensions	Criteria	References
Financial (Dimension 1)	Price fairness (criterion 1)	[7], [8]
	Competitive charges (criterion 2)	[10], [11]
	Payment facilities (criterion 3)	[12], [13]
Functionality (Dimension 2)	Ease of access (criterion 4)	[14],[19]
	Reliability (criterion 5)	[16], [17]
	Customer support (criterion 6)	[16], [17]
Physical conditions (Dimension 3)	Working hours (criterion 7)	[18], [89]
	Hygiene (criterion 8)	[21], [22]
	Location (criterion 9)	[19], [20]

Table 1 represents the 3 dimensions of customer expectations entitled financial (dimension 1), functionality (dimension 2), and physical conditions (dimension 3), which are defined for the house of quality-based evaluation of the healthcare industry. Price fairness (criterion 1), competitive charges (criterion 2), and payment facilities (criterion 3) are employed for the sub-dimensions of financial dimension. The dimension of functionality is also divided into 3 criteria: ease of access (criterion 4), reliability (criterion 5), and customer support (criterion 6), while the criteria of physical conditions are defined as working hours (criterion 7), hygiene (criterion 8), and location (criterion 9). However, Table 2 shows the technical requirements of new service development competencies for healthcare investments.

TABLE 2. Technical requirements of new service development competencies

Technical Requirements	References
Organizational capacity (alternative 1)	[22], [25]
Technological infrastructure (alternative 2)	[13], [24]
Functionality (alternative 3)	[24], [25]
Operational convenience (alternative 4)	[23], [25]
Cost management (alternative 5)	[26], [90]

In Table 2, the technical requirements of HoQ are determined as organizational capacity (alternative 1), technological infrastructure (alternative 2), functionality (alternative 3), operational convenience (alternative 4), and cost management (alternative 5) to measure the new service development competencies of healthcare investments.

Stage 2: Weight the criteria and dimensions of customer expectations for the healthcare industry

The extension of the DEMATEL method based on the HFLTSs, 2-tuple linguistic information and IVIFSs is

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

applied to determine the weights of the dimensions and criteria of customer expectations for the healthcare industry. To this end, three experts who are academicians and top managers in the healthcare industry are selected. They have at least ten years of experience and research in the areas of healthcare management and economics. Linguistic choices are then provided by decision makers in order to construct the relation matrices and define the degrees of influence among the criteria and dimensions. Table 3 shows the linguistic scales.

TABLE 3. Linguistic scales

CT	AT	Evaluation Numbers
No influence (n)	Worst (w)	1
somewhat influence (s)	Poor (p)	2
medium influence (m)	Fair (f)	3
high influence (h)	Good (g)	4
very high influence (vh)	Best (b)	5

Five-point linguistic scales are defined as no influence (n), somewhat influence (s), medium influence (m), high influence (h), and very high influence (vh) for the criteria and dimensions. Similarly, worst (w), poor (p), fair (f), good (g), best (b) are given as a set of linguistic scales for the alternatives. Tables 4-7 present the evaluations.

TABLE 4. Evaluations for dimensions

	DI1			DI2			DI3		
	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3
DI1				ls “m”	bw “m”-“h”	bw “m”-“h”	ls “m”	bw “s”-“h”	ls “m”
DI2	ms “h”	ls “s”	ls “m”				gr “s”	bw “m”-“h”	ms “m”
DI3	ms “m”	ls “m”	bw “m”-“vh”	gr “m”	ms “m”	ms “m”			
DI: dimension; DEC: decision makers; ls: at least; ms: at most; bw: between; gr: greater than									

TABLE 5. Evaluations of criteria of DI1

	CT1			CT2			CT3		
	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3
CT 1				ms “m”	ls “m”	bw “s”-“h”	ls “m”	bw “s”-“vh”	bw “s”-“vh”
CT 2	ls “m”	ls “m”	bw “h”-“vh”				ls “h”	ls “m”	ms “h”
CT 3	gr “m”	ms “h”	bw “m”-“vh”	gr “m”	ms “m”	sm “m”			
CT: criterion; DEC: decision makers; ls: at least; ms: at most; bw: between; gr: greater than									

TABLE 6. Evaluations of criteria of DI2

	CT4			CT5			CT6		
	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3
CT 4				ms “m”	ms “m”	bw “m”-“h”	bw “m”-“vh”	bw “s”-“vh”	bw “h”-“vh”
CT 5	lw “h”	bw “m”-“vh”	ls “h”				ls“m”	ls “h”	ms “m”
CT 6	gr “h”	bw “m”-“h”	ls “m”	gr “h”	bw “h”-“vh”	ms “h”			
CT: criterion; DEC: decision makers; ls: at least; ms: at most; bw: between; gr: greater than; lw: lower than									

TABLE 7. Evaluations of criteria of DI3

	CT7			CT8			CT9		
	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3	DEC1	DEC2	DEC3
CT 7				ms “m”	bw “h”-“h”	lw “h”	bw “s”-“h”	bw “m”-“vh”	bw “m”-“vh”

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

CT 8	ms "h"	ls "m"	bw "m"-"h"				ms "h"	ls "m"	ls "m"
CT 9	ms "h"	ls "h"	ls "m"	bw "m"-"vh"	ms "h"	gr "m"			
CT: criterion; DEC: decision makers; ls: at least; ms: at most; bw: between; gr: greater than; lw: lower than									

In the following step, intuitionistic fuzzy sets based on 2-tuple linguistic information are constructed with the Equations (5)-(9) and the direct relation matrix values are obtained using Formula (10). To this end, the boundaries of the linguistic term sets and the collective evaluations based on 2-tuple linguistic information with the optimistic and pessimistic values are presented in Tables 8 and 9.

TABLE 8. Boundaries

	DI1			DI2			DI3		
	DEC1	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**
DI 1				$[m, vh]$	$[m, h]$	$[m, h]$	$[m, vh]$	$[s, h]$	$[m, vh]$
DI 2	$[n, h]$	$[s, vh]$	$[m, vh]$				$[m, vh]$	$[m, h]$	$[n, m]$
DI 3	$[n, m]$	$[m, vh]$	$[m, vh]$	$[h, vh]$	$[n, m]$	$[n, m]$			

TABLE 9. 2-tuple values

	DI1		DI2		DI3	
	Oc	**Pc**	**Oc**	**Pc**	**Oc**	**Pc**
DI1			(h,.33)	(m,0)	(vh,-.33)	(m,-.33)
DI2	(vh,-.33)	(s,0)			(h,0)	(s,.33)
DI3	(h,.33)	(s,.33)	(h,-.33)	(s,0)		
Oc: Optimistic; Pc: Pessimistic						

Table 10 shows the conversion of these evaluations into the IVIFSs. The optimistic and pessimistic values are converted into the IVIFs with the limits of 2-tuple linguistic values in five-point scales.

TABLE 10. IVIFSs

	DI1	**DI2**	**DI3**
DI1		((.60,.67), (.20,.40))	((.60,.73), (.20,.33))
DI2	((.60,.73), (.10,.20))		((.40,.60), (.20,.27))
DI3	((.60,.67), (.20,.27))	((.40,.53), (.10,.20))	

The direct relation matrix is generated by the values from the attitudinal expected score function with Equation (11) and the matrix is provided using Equation (12). Table 11 presents the relation matrix among the dimensions for the attitudinal value λ:0.

TABLE 11. Direct relation matrix (λ:0)

	DI1	**DI2**	**DI3**
DI1	.00	.70	.70
DI2	.75	.00	.60
DI3	.70	.65	.00

A normalization procedure is applied using Equation (13) and the results are given in Table 12.

TABLE 12. Normalized direct relation matrix (λ:0)

	DI1	**DI2**	**DI3**
DI1	.00	.50	.50
DI2	.54	.00	.43
DI3	.50	.46	.00

Later, the total relation matrix is constructed using Equation (14) and the values of D and E, as well as the weights of the criteria, using Equations (15) and (16). The matrix and weighting results of dimensions are given in Table 13.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

TABLE 13. Total relation matrix (λ:0)

	DI1	DI2	DI3	Weights
DI1	14.51	14.17	13.83	.343
DI2	14.52	13.52	13.48	.331
DI3	14.49	13.83	13.17	.327

Finally, the local and global weighting results of the criteria and dimensions for the attitudinal value λ:0 are represented in Table 14.

TABLE 14. Weights of Criteria and Dimensions (λ:0)

DI	Weights	CT	LW	GW
DI1	.343	CT1	.332	.114
		CT2	.328	.112
		CT3	.340	.117
DI2	.331	CT4	.335	.111
		CT5	.335	.111
		CT6	.330	.109
DI3	.327	CT7	.331	.108
		CT8	.331	.108
		CT9	.339	.111
LW: local weights; GW: global weights				

According to the weighting results we can conclude that, financial (dimension 1) is the most important dimension in the dimension set, whereas physical conditions (dimension 3) is relatively weak. Regarding the customer expectations criteria, price fairness (criterion 1) obtains the best global weight with 11,4%, whilst working hours and hygiene (criteria 7 and 8 respectively) are the weakest criteria with 10.8% weight for the attitudinal value λ:0 of the expected score function.

However, the sensitivity analysis of the weighting results can be also applied by considering the different attitudinal values of the expected score function. The global weighting results are illustrated with several attitudinal values between 0 and 1 in Table 15.

TABLE 15. Global weighting results with several attitudinal values

CT	λ:0	λ:.1	λ:.2	λ:.3	λ:.4	λ:.5	λ:.6	λ:.7	λ:.8	λ:.9	λ:1
CT1	.114	.114	.114	.114	.114	.114	.113	.113	.113	.113	.113
CT2	.112	.112	.112	.112	.112	.111	.111	.111	.111	.111	.110
CT3	.117	.116	.116	.116	.115	.115	.115	.114	.114	.114	.113
CT4	.111	.111	.111	.111	.111	.111	.111	.111	.111	.111	.111
CT5	.111	.111	.111	.111	.111	.111	.111	.111	.111	.111	.111
CT6	.109	.109	.109	.109	.110	.110	.110	.110	.110	.110	.110
CT7	.108	.108	.108	.108	.109	.109	.109	.109	.109	.109	.109
CT8	.108	.108	.109	.109	.110	.110	.110	.111	.111	.112	.112
CT9	.111	.111	.111	.111	.111	.110	.110	.110	.110	.110	.110

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

The global weighting results with several attitudinal values demonstrate that the criteria weights are consistent for all λ values between 0 and 1. This clearly shows that the weighting results can be used to rank the alternatives in the next stage.

Stage 3: Rank the technical requirements of new service development competencies in healthcare investments

In the last stage, the technical requirements of new service development competencies in healthcare investments are evaluated with the house of quality matrix. To this end, an extension of TOPSIS based on hesitant 2-tuple linguistic information and IVIFSs is considered. Table 16 shows the context-free evaluations of decision matrix.

TABLE 16. Evaluations for alternatives

	CT1			CT2			CT3		
	DEC1	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**
AT 1	bw “f”-“g”	ms “f”	ls “f”	f	bw “f”-“g”	ls “p”	bw “p”-“g”	ms “f”	ms “f”
AT 2	bw “f”-“b”	bw “p”-“f”	ls “f”	f	bw “p”-“f”	bw “p”-“g”	bw “f”-“g”	bw “p”-“f”	ms “f”
AT 3	bw “p”-“f”	f	ms “g”	bw “p”-“f”	bw “f”-“g”	ls “f”	f	bw “f”-“g”	bw “f”-“g”
AT 4	bw “g”-“b”	bw “p”-“f”	bw “f”-“g”	b	bw “p”-“f”	G	bw “g”-“b”	bw “p”-“f”	ms “g”
AT 5	f	ls “f”	g	bw “f”-“g”	ls “f”	bw “p”-“f”	f	ls “g”	ms “f”
	CT4			**CT5**			**CT6**		
	DEC1	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**
AT 1	f	ls “g”	ls “f”	bw “p”-“f”	ls “g”	F	bw “p”-“f”	ls “g”	ls “f”
AT 2	ls “f”	ls “g”	ms “f”	bw “p”-“f”	ls “g”	bw “p”-“f”	bw “p”-“f”	ls “g”	bw “p”-“f”
AT 3	f	ls “g”	f	ls “f”	ls “g”	bw “f”-“g”	ls “f”	ls “g”	ls “f”
AT 4	b	bw “p”-“f”	g	ls “g”	ms “f”	ls “g”	bw “g”-“b”	ls “f”	ls “g”
AT 5	bw “p”-“g”	ms “f”	ms “f”	f	ms “f”	F	bw “p”-“f”	F	bw “p”-“g”
	CT7			**CT8**			**CT9**		
	DEC1	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**	**DEC1**	**DEC2**	**DEC3**
AT 1	f	ls “g”	ms “f”	f	ls “f”	ms “g”	bw “p”-“f”	bw “p”-“f”	ms “g”
AT 2	ls “f”	bw “p”-“g”	bw “g”-“b”	bw “f”-“g”	ls “f”	bw “g”-“b”	bw “f”-“g”	ls “f”	bw “g”-“b”
AT 3	ms “f”	bw “p”-“g”	bw “p”-“f”	p	bw “p”-“g”	ls “f”	ms “f”	ls “f”	ms “g”
AT 4	b	ls “f”	bw “g”-“b”	b	ls “f”	bw “g”-“b”	B	ls “g”	bw “g”-“b”
AT 5	bw “p”-“f”	bw “p”-“f”	ls “f”	bw “p”-“f”	bw “p”-“f”	bw “g”-“b”	F	bw “p”-“f”	bw “p”-“f”

AT: alternatives; CT: criterion; DEC: decision makers; ls: at least; ms: at most; bw: between; gr: greater than; lw: lower than

In the following step, the extreme values of linguistic term sets are defined. Collective linguistic evaluations of decision makers are generated with the 2-tuple linguistic information by determining the optimistic and pessimistic limits of evaluations. Table 17 gives the results for the technical requirements of new service competencies in healthcare investments.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

TABLE 17. 2-tuple values of collective linguistic evaluations for alternatives

	CT1		CT2		CT3		CT4		CT5	
	Oc	Pc	Oc	Pc	Oc	Pc	Oc	Pc	Oc	Pc
AT 1	(f,.33)	(p,-.33)	(f,0)	(f,-.33)	(f,.33)	(w,.33)	(g,.33)	(f,.33)	(g,-.33)	(f,0)
AT 2	(g,-.33)	(p,0)	(f,.33)	(p,.33)	(f,.33)	(p,0)	(b,0)	(f,.33)	(g,-.33)	(f,-.33)
AT 3	(p,.33)	(p,0)	(g,0)	(f,-.33)	(g,-.33)	(f,0)	(g,-.33)	(f,.33)	(b,-.33)	(f,0,33)
AT 4	(f,0)	(f,0)	(g,0)	(g,-.33)	(g,-.33)	(p,.33)	(g,0)	(g,-.33)	(g,.33)	(f,0)
AT 5	(f,0)	(f,.33)	(g,0)	(f,-.33)	(g,-.33)	(f,-.33)	(f,.33)	(w,.33)	(f,0)	(p,.33)

	CT6		CT7		CT8		CT9	
	Oc	Pc	Oc	Pc	Oc	Pc	Oc	Pc
AT 1	(g,.33)	(f,0)	(g,-.33)	(f,-.33)	(g,0)	(p,.33)	(f,.33)	(p,-.33)
AT 2	(g,-.33)	(f,-.33)	(b,-.33)	(f,0)	(b,-.33)	(f,.33)	(b,-.33)	(f,.33)
AT 3	(b,0)	(f,.33)	(f,.33)	(p,-.33)	(g,-.33)	(p,.33)	(g,0)	(p,-.33)
AT 4	(b,0)	(g,-.33)	(b,0)	(g,0)	(b,0)	(g,0)	(b,0)	(g,.33)
AT 5	(f,.33)	(p,.33)	(g,-.33)	(p,.33)	(g,-.33)	(f,-.33)	(f,0)	(p,.33)

Decision matrix with IVIFSs is constructed as in Table 18.

TABLE 18. IVIFSs for alternatives

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9
AT1	((.40,.47),(.10,.13))	((.20,.40),(.20,.33))	((.40,.47),(.05,.07))	((.40,.67),(.40,.47))	((.40,.53),(.20,.40))	((.40,.67),(.20,.40))	((.40,.53),(.20,.33))	((.40,.60),(.20,.27))	((.40,.47),(.10,.13))
AT2	((.40,.53),(.10,.20))	((.40,.47),(.20,.27))	((.40,.47),(.10,.20))	((.60,.80),(.40,.47))	((.40,.53),(.20,.33))	((.40,.53),(.20,.33))	((.60,.73),(.20,.40))	((.60,.73),(.40,.47))	((.60,.73),(.40,.47))
AT3	((.20,.27),(.10,.20))	((.40,.60),(.20,.33))	((.40,.53),(.20,.40))	((.40,.53),(.40,.47))	((.60,.73),(.40,.47))	((.60,.80),(.40,.47))	((.40,.47),(.10,.13))	((.40,.53),(.20,.27))	((.40,.60),(.10,.13))
AT4	((.20,.40),(.20,.40))	((.40,.60),(.40,.53))	((.40,.53),(.20,.27))	((.40,.60),(.40,.53))	((.40,.67),(.20,.27))	((.60,.80),(.40,.53))	((.60,.80),(.40,.60))	((.60,.80),(.40,.60))	((.60,.80),(.60,.67))
AT5	((.20,.40),(.40,.47))	((.40,.60),(.20,.33))	((.40,.53),(.20,.33))	((.40,.47),(.05,.07))	((.20,.40),(.20,.27))	((.40,.47),(.20,.27))	((.40,.53),(.20,.27))	((.40,.53),(.20,.33))	((.20,.40),(.20,.27))

Similarly, the defuzzified values of 2-tuple IVIFSs are computed with the attitudinal expected score function (Equation 11) and Table 19 presents the decision matrix for the house of quality-based evaluation (for the attitudinal value λ:0) with the formulas (17) and (18).

TABLE 19. Decision matrix for house of quality-based evaluation (λ:0)

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9
AT1	.65	.50	.68	.50	.60	.60	.60	.60	.65
AT2	.65	.60	.65	.60	.60	.60	.70	.60	.60
AT3	.55	.60	.60	.50	.60	.60	.65	.60	.65
AT4	.50	.50	.60	.50	.60	.60	.60	.60	.50
AT5	.40	.60	.60	.68	.50	.60	.60	.60	.50

In the final step, both the closeness coefficient and the D+ and D- values are computed in order to rank the alternatives and define the technical requirements of new service development competencies in healthcare investments. Table

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

20 illustrates the results of D+, D-, CCi and shows the ranking order for λ:0. The ranking results are provided by listing the values of CCi in descending order.

TABLE 20. Ranking results (λ:0)

AT	D+	D-	CCi	Ranking
AT1	.041	.065	.611	2
AT2	.017	.090	.842	1
AT3	.045	.061	.577	3
AT4	.084	.023	.211	5
AT5	.076	.031	.288	4

The ranking performance of technical requirements are listed as technological infrastructure (alternative 2), organizational capacity (alternative 1), functionality (alternative 3), cost management (alternative 5), and operational convenience (alternative 4) respectively. HoQ-based evaluation results of new service development competencies in healthcare investments demonstrate that technological infrastructure (alternative 2) is the best technical requirement while operational convenience (alternative 4) is the worst/comes last. Additionally, the ranking results of the alternatives are given for other attitudinal values between 0 and 1 in Table 21.

TABLE 21. Comparative ranking results with different attitudinal values

AT	λ:0	λ:.1	λ:.2	λ:.3	λ:.4	λ:.5	λ:.6	λ:.7	λ:.8	λ:.9	λ:1
AT1	2	2	2	2	2	2	2	2	2	2	2
AT2	1	1	1	1	1	1	1	1	1	1	1
AT3	3	3	3	3	3	3	3	3	3	3	3
AT4	5	5	5	5	5	5	5	5	5	5	5
AT5	4	4	4	4	4	4	4	4	4	4	4

The comparative results show that the rankings are same for all the attitudinal values. It is understood that the proposed model is considered coherent when used on the different values of the decision makers' attitudinal characteristics.

VI. DISCUSSIONS AND CONCLUSION

Quality management is a strategic choice for companies in the competitive market environment. Globalization, however, is leading these innovative strategies towards higher quality services and products. Therefore, global markets should deal with new service development strategies more comprehensively. New trends in customer expectations could also affect the strategic priorities of entrepreneurs according to the district's market potential. Hence, companies who are globally competitive should focus on incremental development to help their products and services survive in the market.

Similarly, the concept of quality is the most prominent issue for the healthcare industry. The HoQ technique is frequently applied to analyse the interrelationships between customer expectations and the technical requirements of improving quality. However, as seen in the literature review, health studies with HoQ are extremely limited and none of them employ the integrated methods to evaluate the new service development competencies in the healthcare industry. Thus, this study contributes to the literature of health economics and management by proposing a hybrid decision making approach that includes DEMATEL and TOPSIS based on 2-tuple linguistic information and IVIFSs and adapts HoQ to the new service development competencies in healthcare investments.

The findings illustrate that demanders of healthcare services consider the financial expectations to be the most important factor, while the physical conditions of health services is of significantly less importance. This clearly shows that healthcare firms should provide fair pricing policies together with several payment facilities for their healthcare services. Furthermore, competitive pricing strategies should be generated to obtain consumer loyalty in the healthcare industry. By applying the criteria of the financial expectations of patients and demanders of healthcare services, customer retention could be provided, and this also allows for sustainable growth in the healthcare industry. Frank and Lamiraud [7] focused on consumer behaviour in healthcare industry. The health insurance market in

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

Switzerland was taken into consideration in the analysis process, and the conclusion that pricing strategies should be fair in order to increase customer satisfaction in this area was reached. Winslow [9] also highlighted this situation in his study.

Technological infrastructure, however, is the best ranked technical requirement of new service development competencies, whereas operational convenience gets the worst results in the HoQ-based evaluation of healthcare investments. It is concluded that operational directions with high standards could increase the perceived quality of healthcare investments, which would also satisfy the needs of patients and demanders of health services. Fan et al. [22] focused on the Chinese healthcare sector, and determined that operational mistakes should be minimized if customer satisfaction is to be improved in the healthcare industry.

The main limitation of this study is that the analysis has only been conducted in the health sector. In future studies, new service generation processes in different industries should also be evaluated. In addition to this issue, overall results could also widen for the country level analysis of healthcare industry. Moreover, in future research, different decision-making approaches, such as VIKOR and MOORA, could be applied to undertake a comparative evaluation.

Acknowledgement: This work is partially supported by the Spanish Ministry of Economy and Competitiveness through the Spanish National Research Project PGC2018-099402-B-I00.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

References

[1] Q. Yang, S. Yang, Y. Qian, A. Kraslawski, "Application of House of Quality in evaluation of low rank coal pyrolysis polygeneration technologies" *Energy conversion and management*, vol. 99, pp. 231-241, 2015.

[2] M. Zarei, M. B. Fakhrzad, M. J. Paghaleh, "Food supply chain leanness using a developed QFD model" *Journal of food engineering*, vol. 102, no. 1, pp. 25-33, 2011.

[3] J. R. Hauser, D. Clausing, The House of Quality. *HARVARD BUSINESS REVIEW*, 1988.

[4] A. Kunz, R. L. R. Steinmetz, M. A. Ramme, A. Coldebella, "Effect of storage time on swine manure solid separation efficiency by screening" *Bioresource technology*, vol. 100, no. 5, pp. 1815-1818, 2009.

[5] E. Bas, "An integrated quality function deployment and capital budgeting methodology for occupational safety and health as a systems thinking approach: The case of the construction industry" *Accident Analysis & Prevention*, vol. 68, pp. 42-56, 2014.

[6] R. J. Kuo, Y. H. Wu, T. S. Hsu, L. K. Chen, "Improving outpatient services for elderly patients in Taiwan: a qualitative study" *Archives of gerontology and geriatrics*, vol. 53, no. 2, pp. e209-e217, 2011.

[7] R. G. Frank, K. Lamiraud, "Choice, price competition and complexity in markets for health insurance" *Journal of Economic Behavior & Organization*, vol. 71, no. 2, pp. 550-562, 2009.

[8] A. B. Royalty, N. Solomon, "Health plan choice: price elasticities in a managed competition setting" *Journal of Human Resources*, pp. 1-41, 1999.

[9] C. E. Winslow, "The cost of sickness and the price of health" *Bulletin of the World Health Organization*, vol. 84, no. 2, pp. 153-158, 2006.

[10] M. Gaynor, R. J. Town, "Competition in health care markets" In *Handbook of health economics,* (Vol. 2, pp. 499-637). Elsevier, 2011.

[11] M. Gaynor, W. B. Vogt, "Antitrust and competition in health care markets" *Handbook of health economics*, vol. 1, pp. 1405-1487, 2000.

[12] M. Jegers, K. Kesteloot, D. De Graeve, W. Gilles, "A typology for provider payment systems in health care" *Health policy*, vol. 60, no. 3, pp. 255-273, 2002.

[13] S. E. Kern, D. Jaron, "Healthcare technology, economics, and policy: An evolving balance" *IEEE engineering in medicine and biology magazine: the quarterly magazine of the Engineering in Medicine & Biology Society*, vol. 22, no. 1, pp. 16-19, 2003.

[14] T. F. Akinyemiju, "Socio-economic and health access determinants of breast and cervical cancer screening in low-income countries: analysis of the World Health Survey" *PloS one*, vol. 7, no. 11, 2012.

[15] M. Maheu, P. Whitten, & A. Allen, "*E-Health, Telehealth, and Telemedicine: a guide to startup and success*" John Wiley & Sons, 2012.

[16] P. J. Pronovost, S. M. Berenholtz, C. A. Goeschel, D. M. Needham, J. B. Sexton, D. A. Thompson, ... & E. Hunt, "Creating high reliability in health care organizations" *Health services research*, vol. 41, no. 4p2, pp. 1599-1617, 2006.

[17] P. M. Clarke, & C. Ryan, "Self-reported health: reliability and consequences for health inequality measurement" *Health economics*, vol. 15, no. 6, pp. 645-652, 2006.

[18] K. Karhula, S. Puttonen, A. Ropponen, A. Koskinen, A. Ojajärvi, M. Kivimäki, M. Härmä, "Objective working hour characteristics and work–life conflict among hospital employees in the Finnish public sector study" *Chronobiology international*, vol. 34, no. 7, pp. 876-885, 2017.

[19] A. J. Comber, C. Brunsdon, R. Radburn, "A spatial analysis of variations in health access: linking geography, socio-economic status and access perceptions" *International journal of health geographics*, vol. 10, no. 1, pp. 44, 2011.

[20] M. S. Daskin, L. K. Dean, "Location of health care facilities" In *Operations research and health care,* (pp. 43-76). Springer, Boston, MA, 2005.

[21] M. C. Freeman, M. E. Stocks, O. Cumming, A. Jeandron, J. P. Higgins, J. Wolf, ... V. Curtis, "Systematic review: hygiene and health: systematic review of handwashing practices worldwide and update of health effects" *Tropical Medicine International Health*, vol. 19, no. 8, pp. 906-916, 2014.

[22] D. Fan, L. Cui, M. M. Zhang, C. J. Zhu, C. E. Härtel, C. Nyland, "Influence of high performance work systems on employee subjective well-being and job burnout: empirical evidence from the Chinese healthcare sector" *The International Journal of Human Resource Management*, vol. 25, no. 7, pp. 931-950, 2014.

[23] J. H. Herndon, R. Hwang, K. H. Bozic, "Healthcare technology and technology assessment" *European Spine Journal*, vol. 16, no. 8, pp. 1293-1302, 2007.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

[24] S. G. S. Shah, I. Robinson, "User involvement in healthcare technology development and assessment" *International Journal of Health Care Quality Assurance*, 2006.

[25] K. Adelman, "Promoting employee voice and upward communication in healthcare: the CEO's influence" *Journal of Healthcare Management*, vol. 57, no. 2, pp. 133-148, 2012.

[26] R. Capettini, C. W. Chow, A. H. McNamee, "On the need and opportunities for improving costing and cost management in healthcare organizations" *Managerial Finance*, 1998.

[27] M. N. Vazifehdan, S. A. Darestani, "Green Logistics Outsourcing Employing Multi Criteria Decision Making and Quality Function Deployment in the Petrochemical Industry" *The Asian Journal of Shipping and Logistics*, vol. 35, no. 4, pp. 243-254, 2019.

[28] W. Ho, T. He, C. K. M. Lee, A. Emrouznejad, "Strategic logistics outsourcing: An integrated QFD and fuzzy AHP approach" *Expert Systems with Applications*, vol. 39, no. 12, pp. 10841-10850, 2012.

[29] F. K. Gündoğdu, C. Kahraman, "A novel spherical fuzzy QFD method and its application to the linear delta robot technology development" *Engineering Applications of Artificial Intelligence*, vol. 87, 103348, 2020.

[30] C. Cruz, L. A. Cisternas, A. Kraslawski, "Scaling problems and control technologies in industrial operations: Technology Assessment" *Separation and Purification Technology*, vol. 207, pp. 20-27, 2018.

[31] J. Village, F. A. Salustri, W. P. Neumann, "Using action research to develop human factors approaches to improve assembly quality during early design and ramp-up of an assembly line" *International Journal of Industrial Ergonomics*, vol. 61, pp. 107-119, 2017.

[32] S. De Pelsmaeker, X. Gellynck, C. Delbaere, N. Declercq, K. Dewettinck, "Consumer-driven product development and improvement combined with sensory analysis: A case-study for European filled chocolates" *Food quality and preference*, vol. 41, pp. 20-29, 2015.

[33] T. Lager, "A conceptual framework for platform-based design of non-assembled products" *Technovation*, vol. 68, pp. 20-34, 2017.

[34] A. Erdil, "An Evaluation on Lifecycle of Products in Textile Industry of Turkey through Quality Function Deployment and Pareto Analysis" *Procedia Computer Science*, vol. 158, pp. 735-744, 2019.

[35] E. Bottani, A. Rizzi, "Strategic management of logistics service: A fuzzy QFD approach" *International journal of production economics*, vol. 103, no. 2, pp. 585-599, 2006.

[36] R. T. Wang, "Improving service quality using quality function deployment: The air cargo sector of China airlines" *Journal of Air Transport Management*, vol. 13, no. 4, pp. 221-228, 2007.

[37] M. M. Pandey, "Evaluating the strategic design parameters of airports in Thailand to meet service expectations of Low-Cost Airlines using the Fuzzy-based QFD method" *Journal of Air Transport Management*, vol. 82, 101738, 2020.

[38] G. Büyüközkan, Ç. Berkol, "Designing a sustainable supply chain using an integrated analytic network process and goal programming approach in quality function deployment" *Expert Systems with Applications*, vol. 38, no. 11, pp. 13731-13748, 2011.

[39] L. Na, S. Xiaofei, W. Yang, Z. Ming, "Decision making model based on QFD method for power utility service improvement" *Systems Engineering Procedia*, vol. 4, pp. 243-251, 2012.

[40] M. K. Santos, A. M. Danilevicz, R. M. Tubino, "Environmental service providers assessment: A multi-criteria model applied to industrial waste" *Journal of Cleaner Production*, vol. 159, pp. 374-387, 2017.

[41] W. Zuo, Q. Huang, C. Fan, Z. Zhang, "Quality management of B2C e-commerce service based on human factors engineering" *Electronic Commerce Research and Applications*, vol. 12, no. 5, pp. 309-320, 2013.

[42] D. K. Min, K. J Kim, "An extended QFD planning model for selecting design requirements with longitudinal effect consideration" *Expert Systems with Applications*, vol. 35, no. 4, pp. 1546-1554, 2008.

[43] L. Z. Lin, W. C. Chen, T. J. Chang, "Using FQFD to analyze island accommodation management in fuzzy linguistic preferences" *Expert Systems with applications*, vol. 38, no. 6, pp. 7738-7745.

[44] Y. Geum, R. Kwak, Y. Park, "Modularizing services: A modified HoQ approach" *Computers Industrial Engineering*, vol. 62, no. 2, pp. 579-590, 2012.

[45] C. V. Trappey, A. J. Trappey, S. J. Hwang, "A computerized quality function deployment approach for retail services" *Computers Industrial Engineering*, vol. 30, no. 4, pp. 611-622, 1996.

[46] S. H. Park, S. Ham, M. A. Lee, "How to improve the promotion of Korean beef barbecue, bulgogi, for international customers. An application of

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

quality function deployment" *Appetite*, vol. 59, no. 2, pp. 324-332, 2012.

[47] W. M. Wey, Y. H. Chiu,"Assessing the walkability of pedestrian environment under the transit-oriented development" *Habitat International*, vol. 38, pp. 106-118, 2013.

[48] H. R. Zadry, D. Rahmayanti, L. Susanti, D. Fatrias, "Identification of design requirements for ergonomic long spinal board using Quality Function Deployment (QFD)" *Procedia Manufacturing*, vol. 3, pp. 4673-4680, 2015.

[49] L. A. Zadeh, "Fuzzy sets" Information and control, vol. 8, no.3, pp. 338-353, 1965.

[50] R. M. Rodríguez, Á. Labella, L. Martínez, "An overview on fuzzy modelling of complex linguistic preferences in decision making" *International Journal of Computational Intelligence Systems*, vol. 9, no. sup1, pp. 81-94, 2016.

[51] H. C. Liao, L. Y. Yang, Z. S. Xu, "Two new approaches based on ELECTRE II to solve the multiple criteria decision making problems with hesitant fuzzy linguistic term sets" *Applied Soft Computing*, vol. 63, pp. 223-234, 2018.

[52] F., Herrera, L. Martínez, "A 2-tuple fuzzy linguistic representation model for computing with words" *IEEE Transactions on fuzzy systems*, vol. 8, no. 6, pp. 746-752, 2000.

[53] L. Martínez, R. M. Rodriguez, F. Herrera, "2-Tuple Linguistic Model" In *The 2-tuple Linguistic Model,* (pp. 23-42). Springer, Cham, 2015.

[54] Y. Ou, L. Yi, B. Zou, Z. Pei, "The linguistic intuitionistic fuzzy set TOPSIS method for linguistic multi-criteria decision makings" *International Journal of Computational Intelligence Systems*, vol. 11, no. 1, pp. 120-132, 2018.

[55] M. Liang, J. Mi, T. Feng, B. Xie,"Multi-adjoint based group decision-making under an intuitionistic fuzzy information system" *International Journal of Computational Intelligence Systems*, vol. 12, no. 1, pp. 172-182, 2018.

[56] J. Ye, "Multicriteria fuzzy decision-making method based on a novel accuracy function under interval-valued intuitionistic fuzzy environment" *Expert Systems with Applications*, vol. 36, no. 3, pp. 6899-6902, 2009.

[57] K. Atanassov, "Intuitionistic fuzzy sets" *Fuzzy Sets and Systems*, vol. 20, pp. 87–96, 1986.

[58] K. Atanassov, "Operators over interval-valued intuitionistic fuzzy sets" *Fuzzy Sets and Systems*, vol. 64, pp. 159–174, 1994.

[59] K. Atanassov, G. Gargov, "Interval valued intuitionistic fuzzy sets" *Fuzzy Sets and Systems*, vol. 31, pp. 343–349, 1989.

[60] W. L. Gau, D. J. Buehrer, "Vague sets" *IEEE Transactions on Systems Man and Cybernetics*, vol. 23, pp. 610–614, 1993.

[61] H. Bustince, P. Burillo, "Vague sets are intuitionistic fuzzy sets" *Fuzzy Sets and Systems*, vol. 79, pp. 403–405, 1996.

[62] R. M. Rodríguez, L. Martínez, "An analysis of symbolic linguistic computing models in decision making" *International Journal of General Systems*, vol. 42, no. 1, pp. 121-136, 2013.

[63] R. M. Rodriguez, L. Martinez, F. Herrera, "A group decision making model dealing with comparative linguistic expressions based on hesitant fuzzy linguistic term sets" *Information Sciences*, vol. 241, pp. 28-42, 2013.

[64] L. Martinez, "Sensory evaluation based on linguistic decision analysis" *International Journal of Approximate Reasoning*, vol. 44, no. 2, pp. 148-164, 2007.

[65] R. M. Rodriguez, L. Martinez, F. Herrera, "Hesitant fuzzy linguistic term sets for decision making" *IEEE Transactions on fuzzy systems,* vol. 20, no. 1, pp. 109-119, 2012.

[66] H. Liu, R. M. Rodríguez, "A fuzzy envelope for hesitant fuzzy linguistic term set and its application to multicriteria decision making" *Information Sciences*, vol. 258, pp. 220-238, 2014.

[67] Y. Liu, R. M. Rodríguez, H. Hagras, H. Liu, K. Qin, L. Martínez, "Type-2 fuzzy envelope of hesitant fuzzy linguistic term set: A new representation model of comparative linguistic expression" *IEEE Transactions on Fuzzy Systems,* vol. 27, no. 12, pp. 2312-2326, 2019.

[68] D. F. Li, "TOPSIS-based nonlinear-programming methodology for multiattribute decision making with interval-valued intuitionistic fuzzy sets" *IEEE Transactions on Fuzzy Systems,* vol. 18, no. 2, pp. 299-311, 2010.

[69] S. Narayanamoorthy, S. Geetha, R. Rakkiyappan, Y. H. Joo, "Interval-valued intuitionistic hesitant fuzzy entropy based VIKOR method for industrial robots selection" *Expert Systems with Applications*, vol. 121, pp. 28-37, 2019.

[70] A. Gabus, A., and E. Fontela, *"Perceptions of the World Problematique: Communication Procedure, Communicating with those Bearing Collective Responsibility"* Battelle Geneva Research Centre, Geneva, Switzerland, 1973.

[71] H. Dinçer, Ü. Hacıoğlu, S. Yüksel, "Balanced scorecard based performance measurement of

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3117796, IEEE Access

European airlines using a hybrid multicriteria decision making approach under the fuzzy environment" *Journal of Air Transport Management*, vol. 63, pp. 17-33, 2017.

[72] L. Abdullah, N. Zulkifli, "Integration of fuzzy AHP and interval type-2 fuzzy DEMATEL: An application to human resource management" *Expert Systems with Applications*, vol. 42, no. 9, pp. 4397-4409, 2015.

[73] Q. Zhou, W. Huang, Y. Zhang, "Identifying critical success factors in emergency management using a fuzzy DEMATEL method" *Safety science*, vol. 49, no. 2, pp. 243-252, 2011.

[74] W. W. Wu, Y. T. Lee, "Developing global managers' competencies using the fuzzy DEMATEL method" *Expert systems with applications*, vol. 32, no. 2, pp. 499-507, 2007.

[75] Q. Jun, H. Dinçer, S. Yüksel, "Stochastic hybrid decision-making based on interval type 2 fuzzy sets for measuring the innovation capacities of financial institutions" *International Journal of Finance Economics*, 2020.

[76] Q. Deng, X. Liu, H. Liao, "Identifying critical factors in the eco-efficiency of remanufacturing based on the fuzzy DEMATEL method" *Sustainability*, vol. 7, no. 11, pp. 15527-15547, 2015.

[77] G. George-Ufot, Y. Qu, I. J. Orji, "Sustainable lifestyle factors influencing industries' electric consumption patterns using Fuzzy logic and DEMATEL: The Nigerian perspective" *Journal of Cleaner Production*, vol. 162, pp. 624-634, 2017.

[78] C. Khompatraporn, T. Somboonwiwat, "Causal factor relations of supply chain competitiveness via fuzzy DEMATEL method for Thai automotive industry" *Production Planning Control*, vol. 28, no. (6-8), pp. 538-551, 2017.

[79] Z. Tang, H. Dinçer, "Selecting the House-of-Quality-Based Energy Investment Policies for the Sustainable Emerging Economies" *Sustainability*, vol. 11, no. 13, 3514, 2019.

[80] L. Abdullah, N. Zulkifli, H. Liao, E. Herrera-Viedma, A. Al-Barakati, "An interval-valued intuitionistic fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management" *Engineering Applications of Artificial Intelligence*, vol. 82, pp. 207-215, 2019.

[81] J. Wu, F. Chiclana, "Non-dominance and attitudinal prioritisation methods for intuitionistic and interval-valued intuitionistic fuzzy preference relations" *Expert Systems with Applications*, vol. 39, no. 18, pp. 13409-13416, 2012.

[82] Y. J. Lai, T. Y. Liu, C. L. Hwang, "Topsis for MODM" *European journal of operational research*, vol. 76, no. 3, pp. 486-500, 1994.

[83] D. L. Olson, "Comparison of weights in TOPSIS models" *Mathematical and Computer Modelling*, vol. 40, no. 7-8, pp. 721-727, 2004.

[84] J. W. Wang, C. H. Cheng, K. C. Huang, "Fuzzy hierarchical TOPSIS for supplier selection" *Applied soft computing*, vol. 9, no. 1, pp. 377-386, 2009.

[85] F. E. Boran, S. Genç, M. Kurt, D. Akay, "A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method" *Expert Systems with Applications*, vol. 36, no. 8, pp. 11363-11368, 2009.

[86] H. Deng, C. H. Yeh, R. J. Willis, "Inter-company comparison using modified TOPSIS with objective weights" *Computers Operations Research*, vol. 27, no. 10, pp. 963-973, 2000.

[87] D. Yong, "Plant location selection based on fuzzy TOPSIS" *The International Journal of Advanced Manufacturing Technology*, vol. 28, no. 7-8, pp. 839-844, 2006.

[88] X. Q. Wu, Y. Wang, N. Liu, Q. Gao, G. F. Lu, "Evaluation of circular economy development in industrial park based on eco-efficiency theory and TOPSIS approach" *Chinese Journal of Ecology*, vol. 27, no. 12, pp. 2203-2208, 2008.

[89] M. Härmä, "Promoting older workers' job retention and health by working hour patterns" In *Sustainable working lives,* (pp. 249-268). Springer, Dordrecht, 2015.

[90] S. H. Berger, "10 ways to improve healthcare cost management: if your hospital hasn't been achieving cost savings, maybe you need to make--or renew--a commitment to cost management" *Healthcare Financial Management*, vol. 58, no. 8, pp. 76-81, 2015.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/