Healthcare Sustainability Evaluation Using a Hybrid Fuzzy Multi-Criteria Decision-Making Model

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Abstract Developing a sustainable healthcare system directly depends on the level of maturity in environmental, social, and economic practices. Although there are huge number of researches considering environmental, social, and economic aspects, to the best of our knowledge, no approach was found which unifies these dimensions as an integrated method to assess the current status of sustainable development in healthcare organizations. In order to cope with this gap, this article suggests a method for analyzing the sustainability indicator in healthcare systems by manipulating the sustainability dimensions, criteria, and attributes. The following research has collected 62 attributes and 15 criteria for three sustainability dimensions. A new implementation method is also proposed to make this approach applicable in real-world problems. The contributions of this paper can be distinguished as the healthcare system's sustainability level in imprecise conditions is

obtained, the capability of identifying the weak points in implementing sustainability aspects is presented, and a new methodology for collecting the fundamental data for measuring the sustainability level in healthcare systems is given. The findings of this paper assist the practitioners and experts to successfully evaluate the sustainability level of healthcare systems and significantly improve the performance of them.

Keywords Healthcare systems · Sustainable development · Performance evaluation · Medical centers · Fuzzy logic

1 Introduction

Sustainability denotes the concept of achieving the adequate capability to meet the existing needs, without counting on future technologies and abilities. This issue has been highlighted in the past few years because of the agile communication concepts and customer-oriented aims. The government has regulated rules and prohibitions toward the sustainability level of organizations and facilities. Thus, conventional industries and services have changed toward the maximum level of costumers' satisfaction.

A huge amount of industries are now moving toward sustainable operations rather than traditional processes so they can compete in today's markets. In spite of that, more and more researches are being conducted to facilitate this transition for different cases. The researchers are considering sustainability criteria in diverse types of science including engineering [1, 2], business and management [3, 4], energy [5, 6], health science [7, 8], etc. The vast range of sustainable thinking indicates that there are still room for evaluation models which can consider three

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aspects of sustainability simultaneously. Although, on the other hand, applying sustainability practices, especially the ones that are related to environment, may bring some costs for companies at the beginning but if the factors of three aspects are correctly addressed, the company will reach a balance in terms of inputs and outputs.

Sustainable healthcare signifies the ability to treat patients based on the sustainability dimensions, i.e., Social, Environmental and Economic, with concentrating on patient satisfaction instead of profiting. Despite significant expansion of sustainable healthcare facilities at different medical centers and hospitals, the sustainability measurement systems are defined to evaluate the total sustainability index based on some criteria and attributes which are directly related to sustainability dimensions. Total sustainability index indicates the condition of social, economic, and environmental development of healthcare facilities simultaneously.

To the best of authors' knowledge, despite the extensive studies conducted in the context of sustainable healthcare system, still no approach was found to incorporate the relevant sustainability triple bottom line (TBL) attributes and utilizing them in the determination of the sustainability level of a healthcare system. In order to cope with this crucial gap, this study aims at providing a benchmark framework by collecting the attributes from extended review of the literature and classifying them into diverse criteria. This research also introduces a new approach for identifying weak attributes in healthcare system by introducing a new fuzzy performance importance index. The findings of this study assist experts and policymakers to improve the practices of sustainable development in their associated systems.

The innovations and contributions of this study are highlighted as follows:

- A new sustainability evaluation model is proposed considering the sustainability triple bottom line (TBL) attributes in which policymakers would be able to assess the current sustainability level of the healthcare system/medical center. These TBL attributes are collected from extended literature on healthcare systems and sieved based on the experts' opinion. This methodology can be launched as a sound basis for implementing the basic steps of sustainability in diverse healthcare systems.
- An integrated indicator has been proposed by developing a fuzzy aggregation operator which consists of the multiplication of weights and performances of each TBL attribute. This aggregation operator leads to obtain an overall sustainability level after three rounds of calculations, i.e., attribute level, criteria level, and enabler level. Note that the inputs of this operator are

subjective preferences determined by the linguistic terms and based on experts' judgments indeed.

- Fuzzy performance importance index (FPII) is also adopted for determining the impact of every single attribute on the total sustainability level. In other word, each attribute plays an independent role in this system and the FPII index leads DMs to figure out how an attribute enhances/reduces the overall sustainability index through its positive/negative impacts. This tool will also aid policy makers to enhance the overall sustainability by identifying the so-called obstacles and enhancing the quality of them.

The rest of this research has been arranged as follows: in Sect. 2 the literature of healthcare sustainability and fuzzy sets are reviewed. Section 3 introduces the modeling procedure of the proposed approach. In Sect. 4 an illustrative case is resolved according to the proposed framework which indicates the flexibility and wide application of the proposed methodology in real-world cases, and also, discusses the results obtained and elucidates the implications of this study on both theoretical and practical aspects. Section 5 is the conclusions including the drawbacks and findings of the study.

2 Background of Healthcare Sustainability and Fuzzy Evaluation Models

In this section, we review the state-of-the-art literature of sustainability in healthcare systems and fuzzy theory which both have been unified to establish the proposed model. Note that these studies are reviewed in order to show similar works and reveal the necessity of the proposed approach, indeed.

2.1 The Background of Sustainability in Healthcare Systems and Fuzzy Theory

Considering the background of sustainability, Shi et al. worked on sustainable transportation management (STM) to investigate dynamic interactions among diverse dimensions of an STM [9]. Sharma [10] proposed a conceptual sustainable model for green building and proved that the stakeholders play an active role in the determination of sustainability in green building. García-Segura et al. [11] have elaborated a novel optimized sustainable bridge design under uncertainty by obtaining a Pareto set of solutions using multi-objective optimization. These researches mostly contribute to obtain the total sustainability index in order to monitor the situation of economic, social, and environmental aspects and recommend some modifications with the aim of improving the total quality.

Obtaining the total sustainability index will aid the improvement process of sustainability toward healthcare systems. By accepting the total sustainability index as a variable in mathematical space, the concept of uncertainty will also be inevitable as well. Dealing with these types of uncertainties is almost possible with defining fuzzy sets and fuzzy theory over them.

There are also diverse researches with the background of healthcare systems and healthcare sustainability in order to enhance the quality of services and treatments by developing environmental factors, social communities, and economic issues of medical centers and hospitals. Juan et al. [12] proposed an optimized model for the hospital's environment sustainability by applying a genetic algorithm. They developed a decision model that searches for hospital environment conditions and suggests an optimized sustainable environment for the corresponding hospital. Castro et al. [13] found that the main barrier for leading a sustainable environment in hospitals is building-related problems. They pointed out that the main problem which causes a lower environmental sustainability index is that there are no effective methods to aid designing team in order to introduce the sustainability infrastructures in their work. Hussain et al. [14] investigated the supply chain concept through the healthcare system. They used Stakeholder theory and SIPOC charts to explore the social sustainability level and motivators, obstacles, and enablers from the stakeholder's perspective. The outcome is a unified method for developing the measures of social sustainability across the supply chain in healthcare systems. In the paper presented by Chauhan and Singh [15], a hybrid multi-criteria decision-making method is proposed to select an appropriate location for healthcare wastes. While these type of waste are so hazardous and pestiferous, the dumping process is so vital. The model that is suggested by this paper applies fuzzy AHP and fuzzy TOPSIS to obtain the optimized location for dumping healthcare waste. Rahman et al. [16] developed a gray-based model to evaluate the key performance indicators of healthcare systems. The main contribution of this paper is an integrated method that can provide decision makers with some criteria about a healthcare system, which is called the key performance indicators, to evaluate the whole performance of a hospital with gray theory in imprecise environment.

Campion et al. [17] have investigated through the effects of custom packs and cotton products that are given to patients for specific times. The study proposes that these types of materials could be reused instead of being dumped. The retrieval process will affect the environmental aspect of sustainability in healthcare systems. Furthermore, a new custom pack is proposed which is more flexible for recycling and retrieving. Stevanovic et al. [18] elaborated a novel method for applying the expert's

opinion about choosing a unified and optimized method as an assessment methodology for appraising the sustainability status of a hospital in Flanders. The expectations of experts are established a SWOT matrix to conclude a more consistent evaluation method based on a quantitative approach. Goh and Marimuthu [19] introduced Organizational Commitment as a new dimension to the evaluation of sustainability in healthcare systems. This concept is utilized as the term "social cohesion" as a criterion for social sustainability dimension in the presented study. Ng and Luk [20] proposed a model in accordance with patient satisfaction by assigning some criteria and attributes. They applied the Rodgers method to rank these attributes in order to figure out the fundamental points. The results concluded that "provider attitude," "efficacy," "accessibility," and "technical competence" are the main attributes that affect the total satisfaction level.

As sustainability has been regulated for being implemented in healthcare systems, and while the social sustainability is one of the dimensions for improving the total sustainability, the patient satisfaction should be considered as one of the most important attributes in the calculations of sustainability. In this article, the patient satisfaction is considered as a social sustainability subset and is divided to diverse criteria to consider the expectations and needs from different points of view such as "Equity," "Quality of Life," and etc. Lin et al. introduced a unified fuzzy-based multi-layer step by step model to obtain the total sustainability index based on predefined criteria, attributes, and enablers related to a specific aspect of sustainability. This model contributes to obtain an approximate of sustainability index in an imprecise environment considering the risks and uncertainties. The method will use linguistic terms to report the performance of each attribute using a questionnaire or an expert's judgment. Then fuzzy membership function (usually triangular fuzzy membership function) is used to allocate the linguistic terms with predefined corresponding fuzzy numbers. Furthermore, an easy fuzzy operator is used to obtain the fuzzy index of each level using fuzzy arithmetical rules. The final fuzzy sustainability index (FSI) is calculated by the incorporation of all attributes, criteria, and enablers. Once the fuzzy sustainability index is obtained, the performance situation of each attribute will be calculated using fuzzy performance importance index (FPII). This indicator will identify the obstacles and weaker attributes which require recommendations and modifications for enhancement of the total quality [21]. Table 1 indicates the literature on fuzzy models that have been utilized to evaluate healthcare systems.

The performance evaluation of sustainability in healthcare facilities consists of three major levels. At the first level, the enablers are defined as the dimensions of

Table 1 Reference, research content, and method

Study	Method	Summary
Otay et al. [22]	Intuitionistic fuzzy AHP & DEA	Intuitionistic fuzzy AHP has been developed to obtain the weights of the criteria. IF-DEA has been also employed to evaluate the performance of the criteria
Mishra et al. [23]	Interval-valued intuitionistic fuzzy COPRAS	Proposed a novel method based on the Complex Proportional Assessment (COPRAS) with multi-criteria decision making for interval-valued intuitionistic fuzzy sets
Li et al. [24]	Interval-valued fuzzy DEMATEL-TOPSIS	The weights of the evaluation criteria are determined by the interval-valued fuzzy DEMATEL method, and the prioritization of the alternatives is determined by the interval-valued fuzzy TOPSIS
Lai [25]	Fuzzy AHP	The study proposes a feasible evaluating approach based on fuzzy AHP to decide the sustainability priority of various types of virtual communities in healthcare industry
Mishra et al. [26]	Intuitionistic fuzzy EDAS	Proposes a novel method called evaluation based on distance from average solution (EDAS) framework based on parametric divergence measures under intuitionistic fuzzy environment
Suresh et al. [27]	Conventional fuzzy approach	Identified some enablers, criteria, and attributes for leanness. Then, the above measures in the case hospital are assessed by using fuzzy logic approach
Ghadimi and Heavey [28]	Fuzzy Inference Systems	Sustainability evaluation of suppliers specifically operating in medical device industry using an efficient Fuzzy Inference System (FIS)
Büyükoçkan et al. [29]	Fuzzy AHP	The concept and factors of service quality are examined. A fuzzy AHP is structured to evaluate the proposed service quality framework

sustainability. The second level consists of criteria which are related to each dimension and the third level consists of extensive attributes trying to elaborate with the prerequisites of each dimension. These attributes are mostly collected from the literature review or expert's judgment in order to address the corresponding criteria with a high level of reliability. In this research, sixty-two attributes are collected from literature and expert's judgment. The corresponding articles and researches are addressed after each attribute. Fifteen criteria are chosen for three dimensions that are shown in Fig. 1.

2.2 Gap Analysis and the Proposed Framework

The literature review demonstrated that healthcare systems have to move from the conventional routines to a more appropriate patient-oriented sustainable way with the intention of dealing with today's competitive business atmosphere. The implementation of sustainable approaches also met with some limitations. Despite the numerous studies that have concentrated on defining sustainability and dimensions in healthcare facilities, there is still need for a unified method that simultaneously evaluates the sustainability performance condition and identifies the obstacles and barriers that are diminishing the total sustainability. The following approach will contribute to filling the following gaps. First, a novel measurement tool is proposed by collecting information about the different dimensions of sustainability in healthcare systems, second, it will contribute to evaluate the sustainability situation of healthcare systems in imprecise and vague conditions by

using fuzzy logic. Third, this paper presents the trapezoidal fuzzy sustainability index to improve the eminence of results as well. Thus, a three-layer multi-attribute hierarchical model is introduced to optimize the sustainability level by identifying obstacles and improving them.

In order to explain the proposed method briefly, after collecting and categorizing attributes in three dimensions, the performance situation of each attribute will be determined by expert's judgment or a questionnaire from the employees. These situations will be considered for each individual attribute as linguistic terms like "Very Good," "Fair," and "Very Poor" or etcetera. These verbal terms are allocated with matching trapezoidal fuzzy numbers, which have been determined with expert's skill, to bring them into mathematical space. Considering the contribution of this information and fuzzy weight operator, the fuzzy index will be obtained at each level. The final sustainability indicator will be obtained once calculation of the three levels is done. Then it will be matched with the predefined conditions using the Euclidean method to express the current status for the sustainability. The fuzzy performance importance index (FPII) will also report a total situation of attribute effects on total sustainability. The comparison of these FPII with the threshold set by decision makers will help to identify the obstacles of healthcare facilities. The main contribution of the following method is the incorporation of trapezoidal fuzzy sets which leads to the obtained results to be more tangible and accurate.

Fig. 1 A systematic framework for healthcare sustainability criteria used in this study

3 The Methodology of Healthcare Sustainability Assessment

The main aim of this research is to augment the practices of sustainable development in healthcare systems by developing the sustainability index and identifying relevant obstacles. This occurs by incorporating the quality of each dimension. The improvement of these aspects is directly related to the choice of proper attributes. Table 2 contains the optimized attributes to cover the main aspects. These attributes, criteria, and dimensions can be utilized to establish a questionnaire template for evaluating maturity of healthcare systems from sustainability point of view. Summary of the conceptual methodology used in this article is shown in Fig. 2.

This article introduces the fuzzy sustainability evaluation to obtain the results as Trapezoidal fuzzy sets. The predefined verbal terms and matching fuzzy sets are shown in Table 3.

The incorporation of fuzzy logic and sustainability index will conclude a multi-layer step by step approach defined in Lin et al. [21] as below:

Step 1: After demonstrating the final judgments about each attribute, the linguistic terms will be replaced with fuzzy sets (refer to Table 3).

$$P_{ij} = \frac{\sum W_{ijk} \times P_{ijk}}{\sum W_{ijk}}, \quad \sum W_{ijk} = 1, \quad (1)$$

where P_{ijk} and W_{ijk} signify the performance and weight of the k th attribute of the j th criteria of the i th dimension, respectively. The final result obtained by using Eq. (1) will be the total fuzzy sustainability index of the healthcare system (FHSI).

Step 2: Use Eq. (2) to obtain the distances between FHSI and each Language Expression Label (refer to Table 4). The corresponding label of the least distance will be identified as the status of sustainability [30].

$$\sigma(\text{FHSI}, \text{LEL}_i) = \sqrt{\sum_{x \in u} \{f_{\text{FHSI}}(x) - f_{\text{LEL}}(x)\}^2} \quad (2)$$

$$u = \{x_0, x_1, \dots, x_m\}$$

Step 3: In this step, we will identify the barriers through healthcare systems and will improve them to reinforce the overall sustainability. The fuzzy performance importance index (FPII) implies a total expression for the

Table 2 The healthcare system sustainability enablers, criteria, and attributes

Healthcare sustainability dimensions	Healthcare sustainability criteria	Healthcare sustainability attributes
Social sustainability (HS ₁)	Equity (HS ₁₁) [32]	Impartial employment system (HS ₁₁₁) [33]
		Human and staff rights (HS ₁₁₂) [32]
		Involvement of employees in decision making (HS ₁₁₃) [33]
		Patient rights (HS ₁₁₄) [34]
		Equal and timely payment system (HS ₁₁₅) [35]
	Human safety, security, and health (HS ₁₂)	Medical Malpractice level (HS ₁₂₁) [36]
		Providing insurance for all staff (HS ₁₂₂)
		Prevention of medical equipment losses (HS ₁₂₃) [37]
		Surveillance cameras (HS ₁₂₄) [33]
		Safety reminder panels (HS ₁₂₅) [33]
	Community and social cohesion (HS ₁₃) [32]	Employment stability (HS ₁₃₁) [38]
		Paging systems condition (HS ₁₃₂) [39]
		Inter-professional relations between doctors and nurses (HS ₁₃₃) [40]
		Cultural and workforce diversity (HS ₁₃₄) [41]
		Accessibility to amenities and public transport (HS ₁₃₅) [13]
	Community livability (HS ₁₄) [32]	Accessibility to the healthcare system (HS ₁₄₁) [42]
		Referral rate (HS ₁₄₂) [43]
		Patient transfer status (HS ₁₄₃) [44]
	Government facilities (HS ₁₅)	Acceptance of insurance (HS ₁₅₁) [45]
		Medication preparation and pharmacy updates (HS ₁₅₂) [46]
		Public center's funding (HS ₁₅₃)
	Training and development (HS ₁₆) [32]	First aid training is provided to employees (HS ₁₆₁) [33]
		Fire extinguisher and safety training (HS ₁₆₂) [33]
		Ergonomic behaviors (HS ₁₆₃)
		Knowledge management (HS ₁₆₄) [47]
		Maintenance of the building (HS ₁₇₁) [33]
Quality of life (HS ₁₇)		Restrooms daily cleaning (HS ₁₇₂) [48]
		Patient pack quality (HS ₁₇₃)
		Caring behaviors (HS ₁₇₄) [49]
		Foodservice quality (HS ₁₇₅) [50]
		Fair complaint handling for patients (HS ₁₇₆) [51]

Table 2 continued

Healthcare sustainability dimensions	Healthcare sustainability criteria	Healthcare sustainability attributes
Economic sustainability (HS ₂)	Economic productivity (HS ₂₁) [32]	Staff salary and income, per capita (HS ₂₁₁) [52]
		Competitive advantages (HS ₂₁₂)
		Operational efficiency (HS ₂₁₃) [53]
		Budgeting condition (HS ₂₁₄) [54]
		Return on equity (HS ₂₁₅) [33]
		Dependence on bank loans (HS ₂₁₆) [33]
		General economic dependence (HS ₂₁₇) [33]
		Input–output balancing level (HS ₂₂₁) [55]
		Responses to patients demand (HS ₂₂₂)
		Health center availability (HS ₂₂₃) [56]
Environmental sustainability (HS ₃)	Health services efficiency (HS ₂₂) [55]	Parking facilities (HS ₂₂₄)
		Employment opportunities (HS ₂₃₁) [57]
		Investment in new development activities or in the improvement of the same activity (HS ₂₃₂) [33]
		Utilization of new technologies in order to improve efficiency and effectiveness (HS ₂₃₃)
		Population changes (HS ₂₃₄)
		Input price inflation (HS ₂₃₅) [58]
	Economic development (HS ₂₃)	Reduction in material consumption (HS ₃₁₁) [33]
		Reduction in energy consumption (HS ₃₁₂) [33]
		Control on water pollution (HS ₃₁₃) [33, 59]
		Reduction of air emissions (HS ₃₁₄) [33]
		The initial capital costs (HS ₃₂₁)
		Energy usage per unit area (HS ₃₂₂) [13]
	Pollution prevention (HS ₃₁) [32]	Construction-waste recycling (HS ₃₂₃) [13]
		Reduce the density of construction (HS ₃₂₄) [13]
		Environmental impact associated with the life cycle of buildings (HS ₃₃₁) [13]
		Consumption of natural resources (HS ₃₃₂)
		Reuse of materials (HS ₃₄₁) [13]
		Use of local, recycled, and certified materials (HS ₃₄₂) [13]
	Design perspective (HS ₃₂) [13]	Percentage recyclable materials in patient-caring process (HS ₃₄₃)
		Reuse of previously built and soil (HS ₃₅₁) [13]
		Updating the previous infrastructure (HS ₃₅₂)
	Climate change and outdoor air quality (HS ₃₃) [13]	
	Materials and solid waste (HS ₃₄) [13]	
	Soil use and biodiversity (HS ₃₅) [13]	

effect of the corresponding attribute in total sustainability. For every single attribute, the mentioned value will be computed by using Eq. (3) as below:

$$FPII_{ijk} = W_{ijk}^* \otimes P_{ijk} \quad (3)$$

$$W_{ijk}^* = [1, 1, 1, 1] - W_{ijk},$$

where W_{ijk} represents the weight of the attribute ijk . The fuzzy weighted average or centroid method is used to rank trapezoidal fuzzy numbers as shown in Eq. (4) [31]:

$$R_i = \frac{a + 2b + 2c + d}{6} \quad (4)$$

Step 4. Once the FPII has been obtained for every single attribute, the ones with lower scores than the managerial limit will be sieved as obstacles. By recognizing these obstacles, suggestions from experts could be useful to be applied to corresponding attributes and enhance the total sustainability level.

Fig. 2 The conceptual model used in this study

4 Illustrative Case and Results

In accordance with the proposed model, a numerical case demonstrates the application of sustainability evaluation in real healthcare systems. The case is resolved to simulate performance of the proposed approach in the real case problems appropriately.

4.1 Numerical Case

Once the verbal terms are defined over fuzzy sets, the experts will be asked to fill the performances and weights of attributes with an appropriate verbal terms. The assigned verbal terms for performances and weights for sixty-two attributes, fifteen criteria, and three dimensions are shown in Table 9.

Once the attributes, criteria, and dimensions are allocated with an appropriate linguistic abbreviation, the corresponding replacement (refer to Table 3) will express the conditions in numerical form. While this assignment process was mostly done with triangular fuzzy sets [21], this study prepared a trapezoidal assignment table to replace linguistic terms.

The overall fuzzy healthcare sustainability index will be calculated by a hierarchical process on three levels. This indicator involves all information regarding the situation all pillars of sustainability.

The overall fuzzy healthcare sustainability index will be calculated by using Eq. (1) and the results obtained in level 2.

$$FHSI = [5.49, 6.32, 7.75, 8.43]$$

Once the fuzzy healthcare sustainability index is obtained, it will be matched with language expression labels using the Euclidean distance measure to express the current sustainability status. These labels are shown in Table 4.

Using the Euclidean Eq. (2) every single distance will be obtained as follows:

$$D(FHSI, TS) = \left\{ (5.49 - 7)^2 + (6.32 - 7.75)^2 + (7.75 - 9.25)^2 + (8.43 - 10)^2 \right\}^{1/2} = 3$$

$$D(FHSI, PrS) = 0.49$$

$$D(FHSI, NS) = 3.99$$

$$D(FHSI, PS) = 7.99$$

$$D(FHSI, WS) = 10.99$$

According to the Euclidean measure, the minimum distance will be selected as the current status of sustainability. The results indicate that the fuzzy healthcare sustainability index has been determined as “Precisely Sustainable.” In order to validate the applicability of the proposed model, the results are compared with the crisp approach and the outcomes indicate that both approaches are leading the same conclusion. The results obtained from a crisp approach are shown in Table 10. The comparison of results is also shown in Table 5.

In order to enhance the quality of sustainable development in the system, there is no intention to apply fundamental modifications. By making policies regarding the improvement of the weak points, the overall index will increase dramatically. These changes firstly depend on the identification of obstacles and weak points. Given this, the fuzzy performance importance index of all attributes are calculated and shown in Table 6. In order to illustrate the application of Eqs. (3) and (4), the fuzzy performance

Table 3 Performance rating and importance weights verbal terms and matching fuzzy sets

Performances		Weights	
Verbal terms	Fuzzy sets	Verbal terms	Fuzzy sets
Worst (W)	[0, 0.25, 0.5, 1.5]	Very Low (VL)	[0, 0.025, 0.05, 0.15]
Very Poor (VP)	[1, 1.5, 2.5, 3]	Low (L)	[0.1, 0.15, 0.25, 0.3]
Poor (P)	[2, 2.75, 4.25, 5]	Fairly Low (FL)	[0.2, 0.275, 0.425, 0.5]
Fair (F)	[3, 4, 6, 7]	Medium (M)	[0.3, 0.4, 0.6, 0.7]
Good (G)	[5, 5.75, 7.25, 8]	Fairly High (FH)	[0.5, 0.575, 0.725, 0.8]
Very Good (VG)	[7, 7.5, 8.5, 9]	High (H)	[0.7, 0.75, 0.85, 0.9]
Excellent (E)	[8.5, 9, 9.75, 10]	Very High (VH)	[0.85, 0.9, 0.975, 1]

Table 4 Language expression labels and matching fuzzy sets

Language expression label (LEL _i)	Corresponding TrFS
Tremendously Sustainable (TS)	[7, 7.75, 9.25, 10]
Precisely Sustainable (PrS)	[5, 6.25, 7.75, 8.5]
Naturally Sustainable (NS)	[3.5, 4.25, 5.75, 6.5]
Partially Sustainable (PS)	[1.5, 2.25, 3.75, 4.5]
Weakly Sustainable (WS)	[0, 0.75, 2.25, 3]

importance index of attribute “Equal and timely payment system” is obtained as follows:

$$W_{ijk}^* = [1, 1, 1, 1] - [0.7, 0.75, 0.85, 0.9] \\ = [0.1, 0.15, 0.25, 0.3]$$

$$FPII_{ijk} = [0.1, 0.15, 0.25, 0.3] \otimes [8.5, 9, 9.75, 10] \\ = [0.85, 1.35, 2.44, 3]$$

By applying centroids or fuzzy weighted average, the ranking score will be calculated as follows for this attribute

$$RS_{115} = \frac{0.85 + 2.7 + 4.88 + 3}{6} = 1.90$$

In order to distinguish the obstacles, a threshold value will be set by managers. The attributes which have ranking scores below the threshold will be identified as obstacles. A proper value for the threshold in these cases is the mean

value of all ranking scores. Here the threshold is considered as 1.00. The weaker attributes are identified and shown in Table 6. Twenty-two attributes seem to be weak, out of the total sixty-two attributes. Five attributes from the Environmental aspect, five from economic, and twelve attributes from the social dimension are identified as weak points that need modifications.

The charts of Fig. 3 display the weak attributes of the associated health system. Forming these charts enables managers to distinguish the obstacles within the systems and apply proper modifications.

4.2 Comparative Analysis

In this section, a comparative analysis has been conducted to facilitate the comprehension of the priority of the proposed approach. We have resolved some cases from other researches to validate our results. According to the mathematical approach which has been elaborated throughout the article, it only can cope with the problems which are aiming to obtain an overall indicator for stating the current status of sustainability. Hence, this approach is efficient for models in which there are a huge amount of criteria with specific weights and performances. Given that, three relevant cases are resolved which contain several sustainability criteria. Due to simplicity and preventing confusion, we have summarized the calculations and provided the final

Table 5 Comparison of the results

Method	The obtained index	Range	Status of sustainable development
Fuzzy analysis	[5.49, 6.32, 7.75, 8.43]	2.94	Precisely Sustainable
Crisp analysis	6.92		Precisely Sustainable

Table 6 FPII values and ranking scores of healthcare sustainability

HS_{ijk}	Aggregated fuzzy performance rating	$W_{ijk}^* = [1, 1, 1, 1] - W_{ijk}$	FPII	Ranking score
(HS ₁₁₁)	[5, 5.75, 7.25, 8]	[0.1, 0.15, 0.25, 0.3]	[0.5, 0.86, 1.81, 2.4]	1.37
(HS ₁₁₂)	[5, 5.75, 7.25, 8]	[0, 0.025, 0.1, 0.15]	[0, 0.14, 0.72, 1.2]	0.49*
(HS ₁₁₃)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*
(HS ₁₁₄)	[3, 4, 6, 7]	[0.1, 0.15, 0.25, 0.3]	[0.3, 0.6, 1.5, 2.1]	1.10
(HS ₁₁₅)	[8.5, 9, 9.75, 10]	[0.1, 0.15, 0.25, 0.3]	[0.85, 1.35, 2.44, 3]	1.90
(HS ₁₂₁)	[3, 4, 6, 7]	[0.2, 0.275, 0.425, 0.5]	[0.6, 1.1, 2.55, 3.5]	1.90
(HS ₁₂₂)	[3, 4, 6, 7]	[0.2, 0.275, 0.425, 0.5]	[0.6, 1.1, 2.55, 3.5]	1.90
(HS ₁₂₃)	[5, 5.75, 7.25, 8]	[0.2, 0.275, 0.425, 0.5]	[1, 1.58, 3.08, 4]	2.39
(HS ₁₂₄)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*
(HS ₁₂₅)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*
(HS ₁₃₁)	[7, 7.5, 8.5, 9]	[0.1, 0.15, 0.25, 0.3]	[0.7, 1.12, 2.12, 2.7]	1.65
(HS ₁₃₂)	[3, 4, 6, 7]	[0.1, 0.15, 0.25, 0.3]	[0.3, 0.6, 1.5, 2.1]	1.10
(HS ₁₃₃)	[5, 5.75, 7.25, 8]	[0.2, 0.275, 0.425, 0.5]	[1, 1.58, 3.08, 4]	2.39
(HS ₁₃₄)	[3, 4, 6, 7]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₁₃₅)	[3, 4, 6, 7]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₁₄₁)	[8.5, 9, 9.75, 10]	[0.1, 0.15, 0.25, 0.3]	[0.85, 1.35, 2.44, 3]	1.90
(HS ₁₄₂)	[8.5, 9, 9.75, 10]	[0.2, 0.275, 0.425, 0.5]	[1.7, 2.47, 4.14, 5]	3.32
(HS ₁₄₃)	[7, 7.5, 8.5, 9]	[0.1, 0.15, 0.25, 0.3]	[0.7, 1.12, 2.12, 2.7]	1.65
(HS ₁₅₁)	[7, 7.5, 8.5, 9]	[0.1, 0.15, 0.25, 0.3]	[0.7, 1.12, 2.12, 2.7]	1.65
(HS ₁₅₂)	[5, 5.75, 7.25, 8]	[0.1, 0.15, 0.25, 0.3]	[0.5, 0.86, 1.81, 2.4]	1.37
(HS ₁₅₃)	[5, 5.75, 7.25, 8]	[0.1, 0.15, 0.25, 0.3]	[0.5, 0.86, 1.81, 2.4]	1.37
(HS ₁₆₁)	[8.5, 9, 9.75, 10]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₁₆₂)	[3, 4, 6, 7]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₁₆₃)	[3, 4, 6, 7]	[0.1, 0.15, 0.25, 0.3]	[0.3, 0.6, 1.5, 2.1]	1.10
(HS ₁₆₄)	[3, 4, 6, 7]	[0.2, 0.275, 0.425, 0.5]	[0.6, 1.1, 2.55, 3.5]	1.90
(HS ₁₇₁)	[5, 5.75, 7.25, 8]	[0, 0.025, 0.1, 0.15]	[0, 0.14, 0.72, 1.2]	0.49*
(HS ₁₇₂)	[3, 4, 6, 7]	[0.1, 0.15, 0.25, 0.3]	[0.3, 0.6, 1.5, 2.1]	1.10
(HS ₁₇₃)	[3, 4, 6, 7]	[0.3, 0.4, 0.6, 0.7]	[0.9, 1.6, 3.6, 4.9]	2.70
(HS ₁₇₄)	[7, 7.5, 8.5, 9]	[0.2, 0.275, 0.425, 0.5]	[1.4, 2.06, 3.61, 4.5]	2.87
(HS ₁₇₅)	[8.5, 9, 9.75, 10]	[0, 0.025, 0.1, 0.15]	[0, 0.22, 0.975, 1.5]	0.65*
(HS ₁₇₆)	[8.5, 9, 9.75, 10]	[0, 0.025, 0.1, 0.15]	[0, 0.22, 0.975, 1.5]	0.65*
(HS ₂₁₁)	[7, 7.5, 8.5, 9]	[0.1, 0.15, 0.25, 0.3]	[0.7, 1.12, 2.12, 2.7]	1.65
(HS ₂₁₂)	[5, 5.75, 7.25, 8]	[0.1, 0.15, 0.25, 0.3]	[0.5, 0.86, 1.81, 2.4]	1.37
(HS ₂₁₃)	[3, 4, 6, 7]	[0.3, 0.4, 0.6, 0.7]	[0.9, 1.6, 3.6, 4.9]	2.70
(HS ₂₁₄)	[3, 4, 6, 7]	[0.2, 0.275, 0.425, 0.5]	[0.6, 1.1, 2.55, 3.5]	1.90
(HS ₂₁₅)	[5, 5.75, 7.25, 8]	[0.2, 0.275, 0.425, 0.5]	[1, 1.58, 3.08, 4]	2.39
(HS ₂₁₆)	[7, 7.5, 8.5, 9]	[0.1, 0.15, 0.25, 0.3]	[0.7, 1.12, 2.12, 2.7]	1.65
(HS ₂₁₇)	[7, 7.5, 8.5, 9]	[0.2, 0.275, 0.425, 0.5]	[1.4, 2.06, 3.61, 4.5]	2.87
(HS ₂₂₁)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*
(HS ₂₂₂)	[3, 4, 6, 7]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₂₂₃)	[3, 4, 6, 7]	[0.2, 0.275, 0.425, 0.5]	[0.6, 1.1, 2.55, 3.5]	1.90
(HS ₂₂₄)	[8.5, 9, 9.75, 10]	[0.3, 0.4, 0.6, 0.7]	[2.55, 3.6, 5.85, 7]	4.74
(HS ₂₃₁)	[3, 4, 6, 7]	[0.2, 0.275, 0.425, 0.5]	[0.6, 1.1, 2.55, 3.5]	1.90
(HS ₂₃₂)	[5, 5.75, 7.25, 8]	[0, 0.025, 0.1, 0.15]	[0, 0.14, 0.72, 1.2]	0.49*
(HS ₂₃₃)	[5, 5.75, 7.25, 8]	[0, 0.025, 0.1, 0.15]	[0, 0.14, 0.72, 1.2]	0.49*
(HS ₂₃₄)	[5, 5.75, 7.25, 8]	[0, 0.025, 0.1, 0.15]	[0, 0.14, 0.72, 1.2]	0.49*
(HS ₂₃₅)	[7, 7.5, 8.5, 9]	[0.2, 0.275, 0.425, 0.5]	[1.4, 2.06, 3.61, 4.5]	2.87

Table 6 continued

HS_{ijk}	Aggregated fuzzy performance rating	$W_{ijk}^* = [1, 1, 1, 1] - W_{ijk}$	FPII	Ranking score
(HS ₃₁₁)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*
(HS ₃₁₂)	[8.5, 9, 9.75, 10]	[0.3, 0.4, 0.6, 0.7]	[2.55, 3.6, 5.85, 7]	4.74
(HS ₃₁₃)	[3, 4, 6, 7]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₃₁₄)	[3, 4, 6, 7]	[0.1, 0.15, 0.25, 0.3]	[0.3, 0.6, 1.5, 2.1]	1.10
(HS ₃₂₁)	[3, 4, 6, 7]	[0.1, 0.15, 0.25, 0.3]	[0.3, 0.6, 1.5, 2.1]	1.10
(HS ₃₂₂)	[5, 5.75, 7.25, 8]	[0.2, 0.275, 0.425, 0.5]	[1, 1.58, 3.08, 4]	2.39
(HS ₃₂₃)	[5, 5.75, 7.25, 8]	[0.1, 0.15, 0.25, 0.3]	[0.5, 0.86, 1.81, 2.4]	1.37
(HS ₃₂₄)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*
(HS ₃₃₁)	[5, 5.75, 7.25, 8]	[0.1, 0.15, 0.25, 0.3]	[0.5, 0.86, 1.81, 2.4]	1.37
(HS ₃₃₂)	[5, 5.75, 7.25, 8]	[0, 0.025, 0.1, 0.15]	[0, 0.14, 0.72, 1.2]	0.49*
(HS ₃₄₁)	[3, 4, 6, 7]	[0, 0.025, 0.1, 0.15]	[0, 0.1, 0.6, 1.05]	0.41*
(HS ₃₄₂)	[8.5, 9, 9.75, 10]	[0.1, 0.15, 0.25, 0.3]	[0.85, 1.35, 2.44, 3]	1.90
(HS ₃₄₃)	[8.5, 9, 9.75, 10]	[0.1, 0.15, 0.25, 0.3]	[0.85, 1.35, 2.44, 3]	1.90
(HS ₃₅₁)	[7, 7.5, 8.5, 9]	[0.1, 0.15, 0.25, 0.3]	[0.7, 1.12, 2.12, 2.7]	1.65
(HS ₃₅₂)	[7, 7.5, 8.5, 9]	[0, 0.025, 0.1, 0.15]	[0, 0.19, 0.85, 1.35]	0.57*

*Obstacles of sustainability

Table 7 Comparative analysis and the obtained results

Research source	Comparative method	Ranking results
<i>Construction social sustainability</i>		
Hendiani and Bagherpour [60]	Trapezoidal fuzzy MCDM	Very socially sustainable
Crisp approach [60]	Crisp MCDM	Very socially sustainable
The proposed approach	Hybrid fuzzy hierarchical approach	Very socially sustainable
<i>Freight transportation systems</i>		
Lin et al. [21]	Fuzzy MCDM	Very sustainable
Hendiani and Bagherpour [61]	Z-number-based MCDM	Very sustainable
Crisp approach [60]	Crisp MCDM	Very sustainable
The proposed approach	Hybrid fuzzy hierarchical approach	Very sustainable
<i>Sustainable development in the manufacturing sector</i>		
Hendiani et al. [62]	Fuzzy integrated TBL	Normally sustainable
Lin et al. [21]	Fuzzy MCDM	Normally sustainable
The proposed approach	Hybrid fuzzy hierarchical approach	Normally sustainable

comparisons. Table 7 indicates the comparative analysis for three different cases.

The comparative analysis shown in Table 7 indicates that the proposed model has performed well in coping with different cases and resulted equally comparing to other approaches. Hence, it can be considered as a basis for evaluating sustainability in healthcare systems.

Table 8 indicates the ranking score of the weak performing attributes, ranked by different approaches including centroid of trapezoidal fuzzy membership, centroid of triangular fuzzy sets, and the alpha cuts of trapezoidal fuzzy membership function.

As it is obvious from Table 8 and Fig. 4, using different ranking approaches may result in different weak performing attributes. For instance, while using alpha-cuts

Table 8 Ranking score of the weak performing attributes using different approaches

Weak performing attributes	Centroid of trapezoidal fuzzy membership	Centroid of triangular fuzzy sets	Alpha cuts ($\alpha = 0.6$)	Threshold
HS ₁₁₂	0.49	0.41	0.912	1.00
HS ₁₁₃	0.57	0.49	1.05	1.00
HS ₁₂₄	0.57	0.49	1.05	1.00
HS ₁₂₅	0.57	0.49	1.05	1.00
HS ₁₃₄	0.41	0.34	0.78	1.00
HS ₁₃₅	0.41	0.34	0.78	1.00
HS ₁₆₁	0.41	0.34	0.78	1.00
HS ₁₆₂	0.41	0.34	0.78	1.00
HS ₁₇₁	0.49	0.41	0.912	1.00
HS ₁₇₅	0.65	0.56	1.185	1.00
HS ₁₇₆	0.65	0.56	1.185	1.00
HS ₂₂₁	0.57	0.49	1.05	1.00
HS ₂₂₂	0.41	0.34	0.78	1.00
HS ₂₃₂	0.49	0.41	0.912	1.00
HS ₂₃₃	0.49	0.41	0.912	1.00
HS ₂₃₄	0.49	0.41	0.912	1.00
HS ₃₁₁	0.57	0.49	1.05	1.00
HS ₃₁₃	0.41	0.34	0.78	1.00
HS ₃₂₄	0.57	0.49	1.05	1.00
HS ₃₃₂	0.49	0.41	0.912	1.00
HS ₃₄₁	0.41	0.34	0.78	1.00
HS ₃₅₂	0.57	0.49	1.05	1.00

approach with $\alpha = 0.6$, the attributes HS₁₁₃, HS₁₂₄, HS₁₂₅, HS₁₇₅, HS₁₇₆, HS₂₂₁, HS₃₁₁, HS₃₂₄, and HS₃₅₂ would not be chosen as the weak performing attributes due to the nature of this ranking method. Since the cutting value (α) is depended on the opinion of decision makers, and may be any values between 0.0 and 1.00, different scenarios may happen using this method. Thus, it is recommended not to use this approach for ranking the fuzzy values related to recognizing weak performing attributes.

Comparing the trapezoidal and triangular fuzzy sets, although there are not significant differences between the amounts, the trapezoidal fuzzy membership function is utilized since it can provide more uncertainty because of the nature of its membership function with four points instead of three. However, the triangular fuzzy membership function with three points (a, b, c) is also a special case of trapezoidal fuzzy membership function with four points (a, b, c, d) when $b = c$.

4.3 Theoretical and Practical Implications

Regarding the increasing pressure for applying sustainability practices in diverse organizations and systems, the organizations firstly have to determine the level of sustainability in enterprise/system. The proposed study contributes to the up-to-date literature of healthcare sustainable development by applications of an index namely fuzzy healthcare sustainability index (FHSI) which provides a benchmark for practitioners/experts who are responsible for sustainable development in their healthcare system.

This research proposes a conceptual outline by collecting 62 vital attributes and classifying them into 15 criteria concerning three pillars of sustainability. Given this, the proposed framework can be set as a sound basis for measuring sustainable development status in diverse systems and organizations.

We can highlight the most important implications on both theory and practice as follows:

Fig. 3 Demonstration of obstacles of health system against the threshold

1. As a theoretical implication, researchers can utilize this study to collect the most relevant evaluation criteria for appraising sustainable development status in other organizations and industries. Besides, this study flattens the way for using trapezoidal fuzzy membership function for handling uncertainty in sustainable development analysis.
2. Taking advantage of the proposed methodology, the current sustainability level of healthcare systems will be obtained straightforwardly. Given this, it can be defined as a project and quite a lot of scholars and managers can be unified as a team with the aim of implementing the proposed method on specific healthcare systems regarding the steps presented in Sect. 4.1.
3. In the light of the proposed framework, efficient policies can be regulated which can enhance the status of sustainability in healthcare systems and consequently lots of privileges will arise including waste prevention in healthcare systems, minimizing the consumption of natural resources, promoting the idea of reusing the materials, etc.

5 Conclusions

This paper presents a novel fuzzy-based evaluation approach for assessing the overall sustainability status in healthcare systems. For each dimension of sustainability,

Fig. 3 continued

fundamental attributes and criteria are considered. Despite the diverse researches and extensive literature review in healthcare sustainability contexts, no appropriate method was found to assess the sustainability level in healthcare

systems. This gap motivated us to develop a unified method to analyze and obtain the current sustainability index in healthcare systems under imprecise environments. Furthermore, this model prepared a multi-layer step-by-step

Fig. 4 Demonstration of ranked weak performing attributes using different approaches

approach to improve the sustainability index by identifying the obstacles and barriers in healthcare systems. The fundamental contributions of the following method will be summarized by the following notes:

The model considered three dimensions of sustainability including social, economic and environments. Three dimensions, fifteen criteria, and sixty-two attributes were encapsulated from the literature to obtain the overall fuzzy healthcare sustainability index (FHSI).

The trapezoidal fuzzy sets are manipulated to cope with the uncertainty through healthcare sustainability with which decision makers will be able to transfer subjective preferences and provide the preliminaries of fuzzy aggregation operator.

The model will lead policy makers to identify the weaker attributes/obstacles that are impeding the improvement of sustainable development in healthcare systems. In the resolved case, twenty-two weak points were found from a set of sixty-two evaluation criteria. Improving the function of these obstacles will contribute to a better sustainability level.

In these type of evaluations, the inputs play the most role in the validation of the results. Thus, it is recommended to enter the inputs with maximum accuracy and based on the implementation steps as mentioned above. As

a further research, it is recommended to consider corporate governance to the modeling procedure. Furthermore, applying other types of fuzzy systems such as interval type-2 fuzzy sets, Z-numbers, and intuitionistic fuzzy sets might be interesting topics for future studies.

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Appendix

See Tables 9 and 10.

Table 9 Allocated dimensions, criteria, and attributes based on expert's judgment

HS_i	HS_{ij}	HS_{ijk}	W_i	W_{ij}	W_{ijk}	P_{ijk}
(HS ₁)	(HS ₁₁)	(HS ₁₁₁)	High	Very High	High	Good
		(HS ₁₁₂)			Very High	Good
		(HS ₁₁₃)			Very High	Very Good
		(HS ₁₁₄)			High	Fair
		(HS ₁₁₅)			High	Excellent
	(HS ₁₂)	(HS ₁₂₁)		Very High	Fairly High	Fair
		(HS ₁₂₂)			Fairly High	Fair
		(HS ₁₂₃)			Fairly High	Good
		(HS ₁₂₄)			Very High	Very Good
		(HS ₁₂₅)			Very High	Very Good
	(HS ₁₃)	(HS ₁₃₁)		High	High	Very Good
		(HS ₁₃₂)			High	Fair
		(HS ₁₃₃)			Fairly High	Good
		(HS ₁₃₄)			Very High	Fair
		(HS ₁₃₅)			Very High	Fair
	(HS ₁₄)	(HS ₁₄₁)		High	High	Excellent
		(HS ₁₄₂)			Fairly High	Excellent
		(HS ₁₄₃)			High	Very Good
	(HS ₁₅)	(HS ₁₅₁)		High	High	Very Good
		(HS ₁₅₂)			High	Good
		(HS ₁₅₃)			High	Good
	(HS ₁₆)	(HS ₁₆₁)		Very High	Very High	Excellent
		(HS ₁₆₂)			Very High	Fair
		(HS ₁₆₃)			High	Fair
		(HS ₁₆₄)			Fairly High	Fair
	(HS ₁₇)	(HS ₁₇₁)		Fairly High	Very High	Good
		(HS ₁₇₂)			High	Fair
		(HS ₁₇₃)			Medium	Fair
		(HS ₁₇₄)			Fairly High	Very Good
		(HS ₁₇₅)			Very High	Excellent
		(HS ₁₇₆)			Very High	Excellent
(HS ₂)	(HS ₂₁)	(HS ₂₁₁)	High	Very High	High	Very Good
		(HS ₂₁₂)			High	Good
		(HS ₂₁₃)			Medium	Fair
		(HS ₂₁₄)			Fairly High	Fair
		(HS ₂₁₅)			Fairly High	Good
		(HS ₂₁₆)			High	Very Good
		(HS ₂₁₇)			Fairly High	Very Good
	(HS ₂₂)	(HS ₂₂₁)		Very High	Very High	Very Good
		(HS ₂₂₂)			Very High	Fair
		(HS ₂₂₃)			Fairly High	Fair
		(HS ₂₂₄)			Medium	Excellent
	(HS ₂₃)	(HS ₂₃₁)		High	Fairly High	Fair
		(HS ₂₃₂)			Very High	Good
		(HS ₂₃₃)			Very High	Good
		(HS ₂₃₄)			Very High	Good
		(HS ₂₃₅)			Fairly High	Very Good

Table 9 continued

HS_i	HS_{ij}	HS_{ijk}	W_i	W_{ij}	W_{ijk}	P_{ijk}
(HS_3)	(HS_{31})	(HS_{311})	Very High	High	Very High	Very Good
		(HS_{312})			Medium	Excellent
		(HS_{313})			Very High	Fair
		(HS_{314})			High	Fair
	(HS_{32})	(HS_{321})		High	High	Fair
		(HS_{322})			Fairly High	Good
		(HS_{323})			High	Good
		(HS_{324})			Very High	Very Good
	(HS_{33})	(HS_{331})		Fairly High	High	Good
		(HS_{332})			Very High	Good
	(HS_{34})	(HS_{341})		Very High	Very High	Fair
		(HS_{342})			High	Excellent
		(HS_{343})			High	Excellent
	(HS_{35})	(HS_{351})		Fairly High	High	Very Good
		(HS_{352})			Very High	Very Good

Table 10 The results of the crisp approach

HS_i	HS_{ij}	HS_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}	R_{ij}	R_i	HSI
(HS_1)	(HS_{11})	(HS_{111})	0.80	0.94	0.80	6.50	7.08	6.99	6.92
		(HS_{112})			0.94	6.50			
		(HS_{113})			0.94	8.00			
		(HS_{114})			0.80	5.00			
		(HS_{115})			0.80	9.40			
	(HS_{12})	(HS_{121})		0.94	0.65	5.00	6.73		
		(HS_{122})			0.65	5.00			
		(HS_{123})			0.65	6.50			
		(HS_{124})			0.94	8.00			
		(HS_{125})			0.94	8.00			
	(HS_{13})	(HS_{131})		0.80	0.80	8.00	5.81		
		(HS_{132})			0.80	5.00			
		(HS_{133})			0.65	6.50			
		(HS_{134})			0.94	5.00			
		(HS_{135})			0.94	5.00			
	(HS_{14})	(HS_{141})		0.80	0.80	9.40	8.90		
		(HS_{142})			0.65	9.40			
		(HS_{143})			0.80	8.00			
	(HS_{15})	(HS_{151})		0.80	0.80	8.00	7.00		
		(HS_{152})			0.80	6.50			
		(HS_{153})			0.80	6.50			
	(HS_{16})	(HS_{161})		0.94	0.94	9.40	6.24		
		(HS_{162})			0.94	5.00			
		(HS_{163})			0.80	5.00			
		(HS_{164})			0.65	5.00			
	(HS_{17})	(HS_{171})		0.65	0.94	6.50	7.43		
		(HS_{172})			0.80	5.00			
		(HS_{173})			0.5	5.00			
		(HS_{174})			0.65	8.00			
		(HS_{175})			0.94	9.40			
		(HS_{176})			0.94	9.40			

Table 10 continued

HS_i	HS_{ij}	HS_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}	R_{ij}	R_i	HSI_i
(HS_2)	(HS_{21})	(HS_{211})	0.80	0.94	0.80	8.00	6.84	6.67	
		(HS_{212})			0.80	6.50			
		(HS_{213})			0.5	5.00			
		(HS_{214})			0.65	5.00			
		(HS_{215})			0.65	6.50			
		(HS_{216})			0.80	8.00			
		(HS_{217})			0.65	8.00			
	(HS_{22})	(HS_{221})		0.94	0.94	8.00	6.65		
		(HS_{222})			0.94	5.00			
		(HS_{223})			0.65	5.00			
		(HS_{224})			0.5	9.40			
		(HS_{225})			0.65	8.00			
	(HS_{23})	(HS_{231})		0.80	0.65	5.00	6.50		
		(HS_{232})			0.94	6.50			
		(HS_{233})			0.94	6.50			
		(HS_{234})			0.94	6.50			
		(HS_{235})			0.65	8.00			
		(HS_{236})			0.80	8.00			
		(HS_{237})			0.65	8.00			
		(HS_{238})			0.65	8.00			
(HS_3)	(HS_{31})	(HS_{311})	0.94	0.80	0.94	8.00	6.57	7.09	
		(HS_{312})			0.5	9.40			
		(HS_{313})			0.94	5.00			
		(HS_{314})			0.80	5.00			
	(HS_{32})	(HS_{321})		0.80	0.80	5.00	6.56		
		(HS_{322})			0.65	6.50			
		(HS_{323})			0.80	6.50			
		(HS_{324})			0.94	8.00			
	(HS_{33})	(HS_{331})		0.65	0.80	6.50	6.50		
		(HS_{332})			0.94	6.50			
	(HS_{34})	(HS_{341})		0.94	0.94	5.00	7.77		
		(HS_{342})			0.80	9.40			
		(HS_{343})			0.80	9.40			
	(HS_{35})	(HS_{351})		0.65	0.80	8.00	8.00		
		(HS_{352})			0.94	8.00			

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