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Development of an Intuitive GUI-Based Fuzzy Multi-Criteria Decision Model for Comprehensive Hospital Service Quality Evaluation and Indexing

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Abstract: Recently, hospital care and other services have become increasingly important for patient satisfaction. Better hospital care and assistance improve patients' medical conditions, management trust, and financial success. In this regard, monitoring and measuring hospital service quality is necessary to improve patient satisfaction and wellness. However, the evaluation of healthcare service quality is a complex and critical task due to its intangible nature. Existing methodologies often struggle to effectively incorporate multiple criteria and address uncertainties inherent in healthcare evaluations. To address these challenges, this research work seeks to develop a comprehensive and robust approach for evaluating hospital service quality to improve decision making and resource allocation for service enhancement. This study aims to evaluate multi-faceted healthcare service quality by combining many criteria and uncertainties into a single index. The model is constructed methodically utilizing fuzzy logic and decision modeling. A dataset collected from diverse healthcare facilities covering various medical specialties and regions is employed to validate and refine the model. Numerous criteria, factors, and dimensions are examined and embedded into the development of the model. Fuzzy logic is used to capture and manage healthcare evaluations' inherent vagueness and imprecision, yielding more accurate and comprehensive outcomes. The model's outcome is the hospital service quality fuzzy index (HSQFI), an easy-to-understand single performance measure. A graphical user interface (GUI) is developed for collecting data, and then it shows the results in the form of barriers and recommendations. Based on the findings, recommendations in terms of barriers (service criteria) to enhance the hospital's service quality have been made. This approach can be a tool for managers or other stakeholders to quickly realize the success of their service plans and pinpoint areas that may need improvement in the future.

Keywords: healthcare; service dimensions; service factors; service criteria; service quality fuzzy index; fuzzy approach; multi-criteria decision making

MSC: 90B50

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1. Introduction

The value of hospital services for patient satisfaction has recently been emphasized greatly due to changing lifestyles and intensifying competition in the healthcare industry. The level of care and cooperation the hospital provides results in higher customer/patient satisfaction and lower recurrence rates. Additionally, increased attention and assistance in the hospital, in addition to taking care of the patient's medical condition, boost the patient's trust in the hospital management and, of course, its financial performance [1]. Certainly, the consideration of service quality has advanced significantly and widely over the last two decades [2,3]. The most crucial concerns in modern healthcare are continuous medical service improvement and patient demand adaptation [4]. It should be defined not simply in terms of treatment outcomes but also by considering the settings in which treatments take place, the environment in which patients receive healthcare, and the link between costs and benefits. All these elements contribute to quality [5]. Not only is high-quality healthcare vital for the operation of medical facilities as a whole, but it is also crucial for the well-being of patients [6]. The World Health Organization (WHO) states that quality healthcare includes the end product (technical quality), how resources are used (economic efficiency), how services are organized, and patient happiness [7]. Healthcare quality is determined not only by objective physical standards but also by sociological as well as psychological standards and notions [8].

Patient satisfaction with hospital services has become increasingly important as healthcare develops and becomes more advanced. Patient/customer satisfaction is largely influenced by how good they consider the quality of the hospital services they receive. This is because patient happiness is a key determinant of how well a healthcare practitioner can provide patient care. Past studies have found a number of factors that influence patient satisfaction in the healthcare sector, as well as regional and cultural variations in how customers perceive services. Thus, this research has focused on developing a patient-perceived hospital service quality assessment model and its evaluation using a case study. This study introduces a novel approach to assessing hospital service quality by developing a fuzzy-based multi-criteria decision model (MCDM). Fuzzy logic is capable of handling complex scenarios [9]. This method uniquely integrates fuzzy logic principles with decision modeling techniques to enhance the accuracy and comprehensiveness of healthcare evaluations. This novel method manifests in the form of a single index, the hospital service quality fuzzy index (HSQFI), making it an innovative method for simplifying the multidimensional assessment of hospital service quality. The scientific impact of this research is significant, considering its potential for readers within healthcare administration, quality management, and decision science, as it offers a new, more reliable method for gauging patient satisfaction and service quality. The HSQFI can help hospital administrators and other key players assess their service plans more successfully and pinpoint areas for future development, improving patient care and satisfaction. In brief, this research work proposes a novel approach to hospital service quality evaluation by combining fuzzy logic, decision modeling, and a user-friendly GUI (graphical user interface). Moreover, a wide range of criteria, factors, and dimensions in evaluating hospital service quality have been considered. Finally, HSQFI is another novel aspect of this research work. The HSQFI is a single easy-to-understand index that can be used by managers and other stakeholders to quickly assess the success of their service plans and identify areas for improvement. This research is significant because it addresses a critical need for a comprehensive and robust approach to evaluating hospital service quality. This is especially important in today's competitive healthcare environment, where hospitals are constantly striving to improve patient satisfaction and quality of care. This research work aims to answer the following research questions (RQs):

- *RQ1: What are the key criteria, factors, and dimensions that should be considered when evaluating hospital service quality?*
- *RQ2: How can uncertainties and biases be minimized when evaluating hospital service quality?*
- *RQ3: How can the results of multi-faceted hospital service quality evaluations be presented in an easy-to-understand manner that can be used to improve decision making and resource allocation?*

The paper is organized into five sections. The literature review of various studies focusing on the service quality of health organizations is included in the subsequent section. Section 3 presents the methodology and steps of the proposed fuzzy-based MCDM approach. Subsequently, the step-by-step methodology adopted and its application is described as a case study in Section 4. While the last section concludes with limitations and future research directions.

2. Literature Review

Researchers around the world have extensively explored the service quality of healthcare research domain. Several research studies have focused on the service quality of health organizations within their countries, and some of them presented generic models. One study showed that understanding how hospital in-patients evaluate service quality performance can improve the current healthcare system's outcomes and service quality, raising satisfied in-patient numbers and keeping patients coming back to the hospitals [10]. Service quality was assessed on five aspects (tangible, reliable, responsiveness, assurance, and empathy), according to Parasuraman et al. [11,12]. The researchers designed an assessment model to assess hospitals' service quality [13–18]. According to Duggirala et al. [19], hospital service quality in a developing country is determined by seven factors: infrastructure, administrative procedures, workforce quality, clinical care protocols, safety, long-term experience, and social responsibility. Aagja and Garg [20] suggested five pillars to improve public hospital service quality: admission, medical care, holistic support, discharge procedure, and public accountability. Numerous elements that can be categorized in various ways influence a patient's perception of a hospital. For example, physical factors (ambiance, infrastructure, tangibles, etc.); interaction factors (staff behavior, expertise, attitude, etc.); and other factors (waiting time, availability, safety, loyalty).

On the contrary, Kondasani and Panda [21] linked the hospital's service quality with patient loyalty. They adopted a questionnaire-based approach and collected data from five private hospitals in India. Their findings showed that patients' perceptions were positively impacted by the interaction between service providers and consumers, the quality of the facilities, and interactions with support staff. Similarly, different service quality measurement models were explored to quantify the service quality of hospitals in Thailand, and feedback was taken from people from four different continents (Asia, Australia, America, and Europe). With varying amounts of quality dimensions and quality attributes, four distinct models for evaluating service quality were established based on the different continents. Asian patients offered a four-facet model comprising twenty items, whereas European patients offered a two-dimensional model with sixteen variables. Patients from Australia similarly revealed a two-dimensional model, but it contained 22 items, whereas Americans offered a three-dimensional model, which contained 17 elements. It was reported that nationality and demographics also significantly affected service satisfaction in addition to size and location factors. Most of the research studies utilized a questionnaire-based approach to obtain the patients' satisfaction levels based on several dimensions [8,22,23].

According to some researchers, patients need more expertise and information to accurately evaluate the technical components of medical services, such as practitioners' diagnostic abilities or surgeons' surgical capabilities. Patients are highly qualified to assess functional quality parameters, like laboratory sanitation, waiting time, etc. [24,25]. Therefore, some researchers only focused on a particular department or service for assessing service quality. For example, Zarie et al. [26] focused on emergency departments' service quality and compared private and public hospitals. A questionnaire was developed based on twenty questions. It was reported that the private hospital's emergency department was better. Some researchers have suggested that even hospitals' supply chain management can significantly affect the service quality dimension and hospital performance [27,28]. Similarly, Han et al. [29] utilized the data obtained from the government initiative of a hotline for patient feedback to measure service quality. The patients' feedback and complaints were utilized to make recommendations to the hospital to improve their service quality. In another research study, the role of digital platforms in healthcare was evaluated, and their impact on patient satisfaction was analyzed [30]. Sharifi et al. [31] presented a comparison of two models, where both models could investigate the level of service quality in healthcare centers. Both models' findings demonstrated an unfavorable void between the service users' expectations and perceptions. Kristinawati et al. [32] utilized a structural equation model (SEM) to analyze the data obtained through questionnaires filled by randomly selected patients at a hospital in Indonesia. The study intended to find the relationship between hospital service quality and customer contentment. It was revealed from the results that there is a significant impact of hospital service quality and satisfaction on loyalty. Patel and Patel [33] employed a combination of confirmatory factor analysis and SEM to analyze the data obtained from a survey of 316 patients from 29 hospitals in India. The goal was to assess how hospital service quality characteristics affected outpatient satisfaction and to identify the demographic factors that influenced that satisfaction. Gavahi et al. [34] adopted QFD (quality function deployment) to improve the service quality in radiology centers. Whereas Junior et al. [35] employed a methodology as a planning tool to measure service quality in a surgical center in Brazil. It was reported that the suggested approach enhanced the decision-making process, increasing the effectiveness of the operation of the surgical center. Duc Thanh et al. [36] proposed a service performance tool to measure the service quality in an oncology public hospital in Vietnam.

Alsawat [37] and Alumran et al. [38] employed a questionnaire-based approach to assess patients' satisfaction with services in the emergency departments of hospitals in Saudi Arabia. Gentili [39] emphasized that the fuzzy technique is an efficient tool in modeling the human power of making decisions based on natural language, and its link with Bayesian inference can make it more effective. The most accredited theory in neuroscience maintains that human reasoning is Bayesian [40]. Kumar and Rambabu [41] proposed a fuzzy technique for order performance by similarity to the ideal solution for ranking the hospitals based on patients' opinions. However, only six factors were considered by them. Another researcher used a fuzzy analytic hierarchy process to rank the quality of four hospitals [42]. Alkafaji and Al-shemary [43] used the hospital consumer assessment of healthcare providers and systems to collect data from the patients and then applied a fuzzy-based method to assess the hospital service quality for two hospitals in Iraq, and several hospitals in the United States of America. The results of the five assessment categories showed that over half of the US hospitals were in the good to very good range. Babroudi et al. [44] presented an integrated model with Z-number theory and a fuzzy cognitive map for health service quality measurement. The results showed that hospital hygiene, hospital reliability, and completeness of the hospital, with ratios of 0.9305, 0.9559, and 0.9268, respectively, were the most significant criteria in enhancing healthcare service quality in a pandemic situation. Some researchers have even applied the fuzzy approach to measure service quality in other industries, such as the hotel industry [45].

Although a lot of research has been performed in the area of healthcare service quality, there are still many gaps that prevent us from fully understanding and accurately measuring and improving hospital service quality. A predominant limitation in the existing literature is the over-reliance on traditional methodologies that often fail to effectively address the multi-dimensional and ambiguous nature of healthcare service quality. Despite a wide variety of performance metrics and evaluation frameworks being proposed, many need help encapsulating diverse criteria and uncertainties in a single, meaningful index. Further, healthcare services' intricate and intangible nature often leads to inconsistent results, reduced reliability, and misinterpretation. Several researchers have presented an assessment model for hospital service quality; however, most of them are based on a qualitative framework, and there is a paucity of mathematical models, and the factors considered in these models are limited and not comprehensive. The necessity for a systematic and reliable technique of evaluating the quality of hospital services as perceived by patients has increased along with healthcare advancement.

Furthermore, the majority of the currently used techniques for evaluating the quality of healthcare are unable to deal with the vagueness and subjective assessment that characterize human perceptions and decision-making processes. This becomes a critical barrier when trying to gain accurate and comprehensive insights into patient satisfaction and care quality. A further research gap is the limited focus on robust and easy-to-understand measures that can be readily implemented by healthcare administrators and stakeholders, limiting the practical applicability of many existing models. These gaps underscore the need for a novel approach to manage healthcare evaluations' inherent uncertainties and complexity and effectively transform the multi-faceted criteria into a single, interpretable performance index. Moreover, as reported in the literature, service quality involves multiple dimensions, and it is not easy to comprehend. Thus, the proposed model has established a single index, so that the management, as well as the customer, can easily evaluate the hospital's service quality. In addition, it has also provided a useful method for hospital management to know about the strengths and weaknesses in their service areas where they can focus on enhancing the service quality of their hospital. To address the issues of vagueness and subjective judgment, the adopted research methodology utilized a fuzzy approach, and the details of the proposed methodology are presented in the subsequent sections.

3. Methodology

It is evident from the above section that researchers have used a variety of assessment techniques to study hospital service quality, where the major concern is to develop a reliable and user-friendly methodology for evaluating the service quality of hospitals to help them improve it and, as a result, satisfaction with care. Below, the suggested methodology enables hospitals to identify areas for improvement in terms of service quality. Additionally, it helps to identify areas or standards that require corrective measures to enhance hospital service quality.

Thus, to identify the hospital service quality indexing model, firstly an expert panel was gathered, and then their opinions were recorded for shortlisted service quality dimensions, factors, and criteria. Additionally, they were asked to evaluate the performance ratings, important weights for the criteria, and importance weights for the factors. For this, linguistic fuzzy concepts were used. The hospital service quality index was subsequently calculated utilizing a fuzzy MCDM evaluation approach by framing a mathematical model. Subsequently, a case study of a hospital in Riyadh, Saudi Arabia, is used to explain the adopted methodology and construct the model step by step, and specifics are given in the subsections below. Thus, an effort is undertaken to introduce the multi-criteria decision-modeling-based methodology to estimate a hospital service performance index, which aims to examine the effectiveness of the service quality and operational policies as well as highlight areas that can be improved in the future.

3.1. Experts Panel

Firstly, a panel of experts (refer to Table 1) was formed to validate the shortlisted hospital service quality factors and hospital service criteria to evaluate the service quality. They were also requested to analyze the performance ratings and importance weights for each service criterion and also asked to assign the desired importance weights for each service dimension. Linguistic terms were considered for this reason. The multi-criteria decision-making evaluation approach was then used to design a mathematical model to estimate the service quality index, which assisted in identifying the factors/barriers impeding service quality improvement. Table 1 shows the details of the experts who took part in this study. These experts had experience in various hospitals, universities, ministries, and healthcare management and responded to the corresponding service criterion.

Table 1. Experts' brief details.

S. No.	Expert Sector	Experience in Years	Organization
1	Academia	22	University
2	Academia	15	University
3	Healthcare	10	Hospital
4	Healthcare	20	Hospital
5	Healthcare	25	Hospital
6	Management	15	Hospital
7	Management	18	Hospital

Table 1. *Cont.*

S. No.	Expert Sector	Experience in Years	Organization
8	Policy making	25	Ministry
9	Academia	21	University
10	Healthcare	20	Hospital
11	Healthcare	17	Hospital
12	Academia	19	University
13	Academia	12	University
14	Quality consultant	23	Hospital
15	Management	16	Hospital

3.2. Identification of Service Quality Dimensions, Factors, and Associated Criteria

An exhaustive search of the literature using sources such as Google Scholar, Science Direct, Scopus, and Web of Science facilitated the selection of service quality areas and criteria. The keywords considered to research the literature were “hospital service quality”, “quality dimensions”, “hospital service development”, “evaluation of service quality”, and “service” with a combination of the Boolean operators “OR” and “AND”. This list of criteria was provided to the specialists for their assessment. As stated in Table 2 below, it was unanimously decided to compress the number of recommended criteria to 78 to measure the quality of any hospital service.

Table 2. Shortlisted hospital service quality dimensions, factors, and criteria.

Service Dimensions (*i*)	Factors (*j*)	k	Criterion	Ref.
PMS	Accessibility and arrival factors	C01	Hospital location	[22]
		C02	Premises parking	[22]
		C03	Emergency parking	[46]
		C04	Public transport	[22]
		C05	Operating hours	[21]
		C06	Visitors’ security	[21]
		C07	Sign boards	[22]
		C08	Ambulance service	[22]
PRM	First point of contact factors/front desk factors	C09	Appointment system	[21]
		C10	Registration process	[2]
		C11	Walk-in facility	[47]
		C12	Understanding need	[21]
		C13	Effective communication	[23]
		C14	The conduct of staff	[47]
		C15	Reception assistance	[38]
		C16	Waiting space	[22]
		C17	Ambiance	[22]
		C18	Waiting time	[21]
		C19	Prompt response	[38]
		C20	Managerial dependence	[47]
PRM	Financial factors	C21	Billing process	[37]
		C22	Precise billing	[47]
		C23	Fairness in billing	[37]
		C24	Discount and insurance	[22]
		C25	Professionalism	[23]
		C26	Timeline of billing	[38]
		C27	Error-free records	[37]

Table 2. *Cont.*

Service Dimensions (*i*)	Factors (*j*)	k	Criterion	Ref.
PPR	Medical consultation/treatment factors	C28	Waiting time	[47]
		C29	On-demand doctors	[47]
		C30	Personalized care	[23]
		C31	Medical examination	[37]
		C32	Medication expertise	[2]
		C33	Patient centered	[37]
		C34	Emotional resonance	[2]
		C35	Medical tests justification	[22]
		C36	Support staff presence	[23]
		C37	Trustworthy care	[47]
PPR	Post-consultation/ treatment factors	C38	Investigations and medications	[22]
		C39	Quick response to request	[37]
		C40	Diet adherence in hospital	[22]
		C41	Accessibility of doctor	[21]
		C42	Adequate doctor's round	[21]
		C43	Post-discharge explanation	[22]
		C44	Discharge procedure	[23]
		C45	Home care instructions	[37]
		C46	Patient feedback	[22]
PMS	Medical support/other services factors	C47	Advanced facilities	[38]
		C48	Clear-organization of facilities	[38]
		C49	Timely reporting of health	[21]
		C50	Reliable healthcare facilities	[47]
		C51	Safe and secure facility	[23]
		C52	Pharmacy service	[21]
		C53	Adequate support staff	[21]
		C54	Facility quality	[38]
		C55	Availability of waiting area	[21]
		C56	Care of privacy	[37]
		C57	Effective hygiene	[21]
		C58	Environmental care	[37]
		C59	Hygiene and comfort level	[22]
		C60	Information clarity	[21]
		C61	Canteen facility	[38]
		C62	Clean hygiene facilities	[37]
PRM	Appearance and behavior (staff and facilities)	C63	Staff neatness	[38]
		C64	Staff clear distinction	[21]
		C65	Patients' security	[47]
		C66	Staff kind demeanor	[23]
		C67	Crowd management skills	[22]
		C68	Effective problem solving	[21]
		C69	Staff punctuality	[23]
		C70	Well-informed staff	[37]
PRM	Customer satisfaction and loyalty	C71	Timely services	[38]
		C72	Sincere responsiveness	[23]
		C73	Flawless medication and treatment	[38]
		C74	Positive atmosphere	[47]
		C75	Patient data privacy	[21]
		C76	Visitors' perception	[37]
		C77	Satisfaction guaranteed	[22]
		C78	Likelihood of recommendation	[47]

Note: PMS: patient management system; PRM: patient relationship management; PPR: patient–physician relationship.

The adopted fuzzy model includes three dimensions, eight factors, and 78 criteria to estimate a fuzzy health service quality index (see Table 2 and Figure 1). The subsequent section details the fuzzy health service quality index evaluation model.

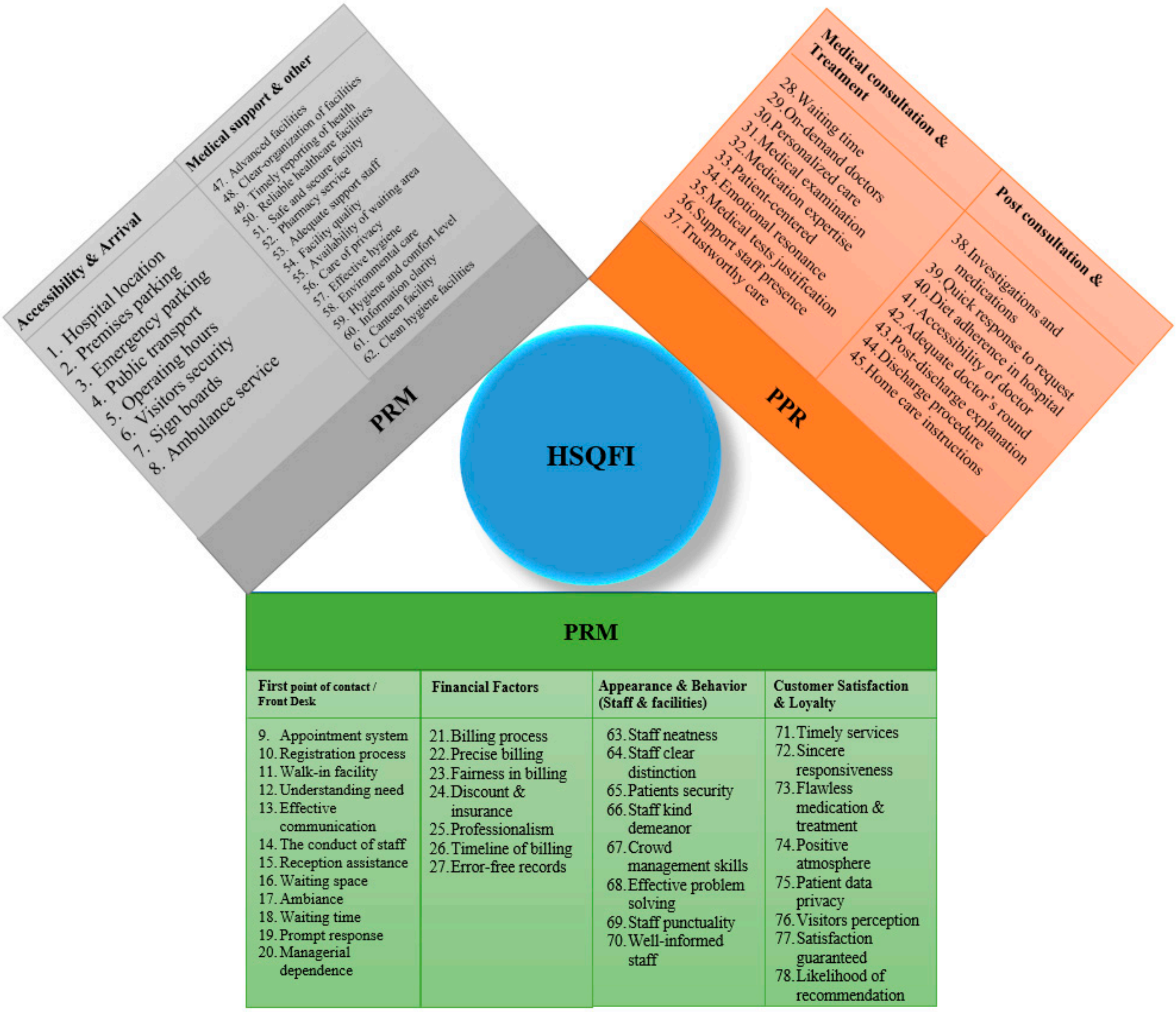


Figure 1. Model representing dimensions, factors, and criteria for hospital service quality assessment.

3.3. Hospital Service Quality Assessment

The administration of the health service organization, in order to stay competitive, should have a suitable, straightforward, and easy-to-execute service quality assessment strategy, which should be based on the World Health Organization's guiding service principles [48]. Assessment of the quality of hospital services primarily depends on patient feedback. Human estimations, which are based on subjective criteria, may be imprecise and vague. This can be addressed using language expressions [49]. However, linguistic expressions are difficult to translate into numerical values. Artificial intelligence offers a "fuzzy logic" approach as a solution to these problems. Here, the service quality indicators' performance ratings and relevance weights were evaluated using the fuzzy logic method [50]. Estimating performance ratings and importance weights for the hospital service criteria is the first step in the evaluation model. Fifteen experts from various health institutions were asked to assign importance weights to each service criterion in the current study. These experts had a wide range of experience in different domains of healthcare. Additionally, they were asked to assess hospital service area importance weights as factors. For this reason, linguistic words were postulated in order to translate them into corresponding fuzzy numbers. Then, a fuzzy evaluation approach was used to calculate the hospital service quality index (HSQI). The Euclidean distance method was utilized to correlate the HSQI with linguistic words in order to determine the service quality level. In addition to this, a criteria performance index (CPI) was estimated to assist in identifying the obstacles preventing the delivery of higher quality services. An illustration of the proposed methodology [49–54] is presented in the flowchart form below (Figure 2), and the next section presents a case study of its application in a Saudi Arabian hospital.

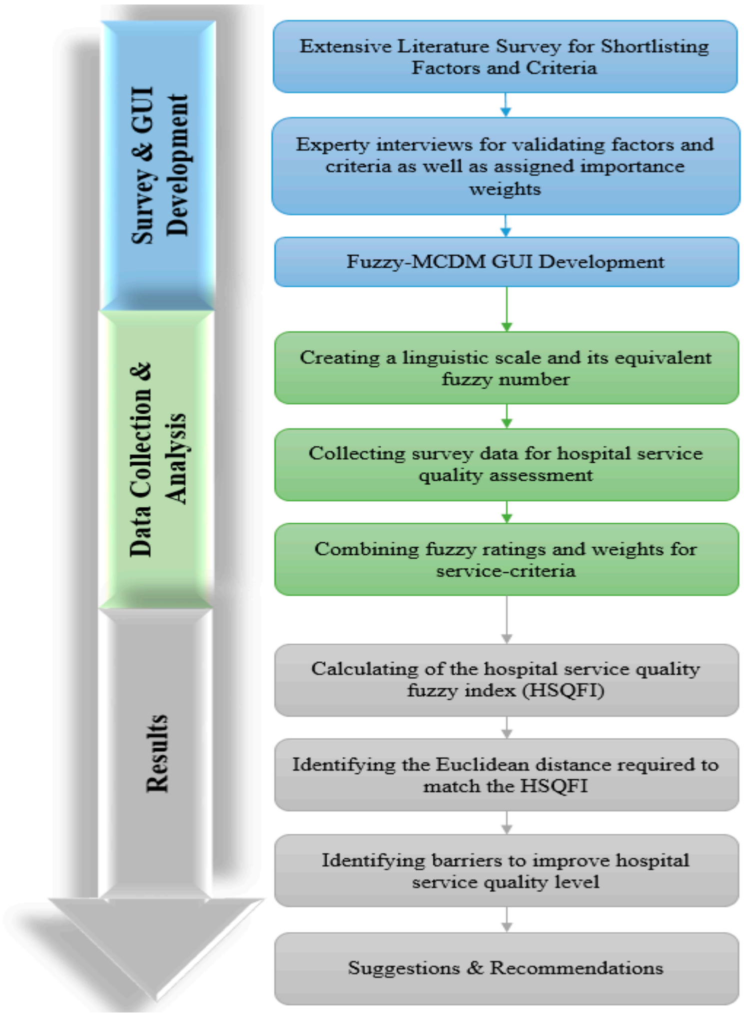
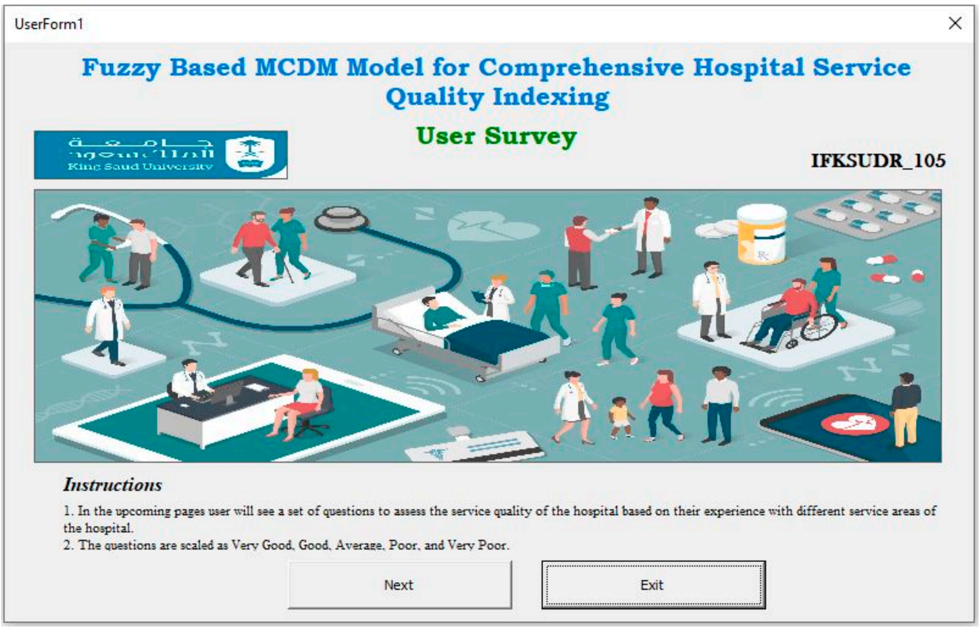


Figure 2. Broad steps to estimate hospital service quality fuzzy index (HQSFI).

3.4. GUI Development

To enhance user-friendliness in the assessment and implementation of the hospital service quality assessment, this study has furthermore developed a graphical user interface (GUI). Microsoft Excel with visual basic application (VBA) was used for the development of the GUI. When it comes to the fuzzy-based MCDM model, this GUI is an indispensable addition as it serves as the primary interface for gathering patient data. Patients can easily input their experiences, perceptions, and opinions about the hospital's service quality through this intuitive, user-friendly interface. By adopting a patient-centric approach, the GUI effectively captures the nuances of patient satisfaction that are often lost in traditional survey methods. Once the data are entered, the GUI uses the integrated fuzzy-based MCDM model to analyze the data, compute the hospital service quality fuzzy index (HSQFI), and provide an easy-to-understand performance measure of the service quality.

One of the most innovative aspects of this GUI is its ability to compute the HSQFI and realize the departments or criteria that need management attention to improve service quality. This helps in transforming the complex assessment data into actionable insights. This user interface, combined with the fuzzy-based MCDM model, significantly enhances the practical applicability of this research, making it a truly useful model in the field of healthcare service quality assessment. Figure 3 shows some screenshots from the developed GUI (other screen shots are available in Appendix A, Figure A1).



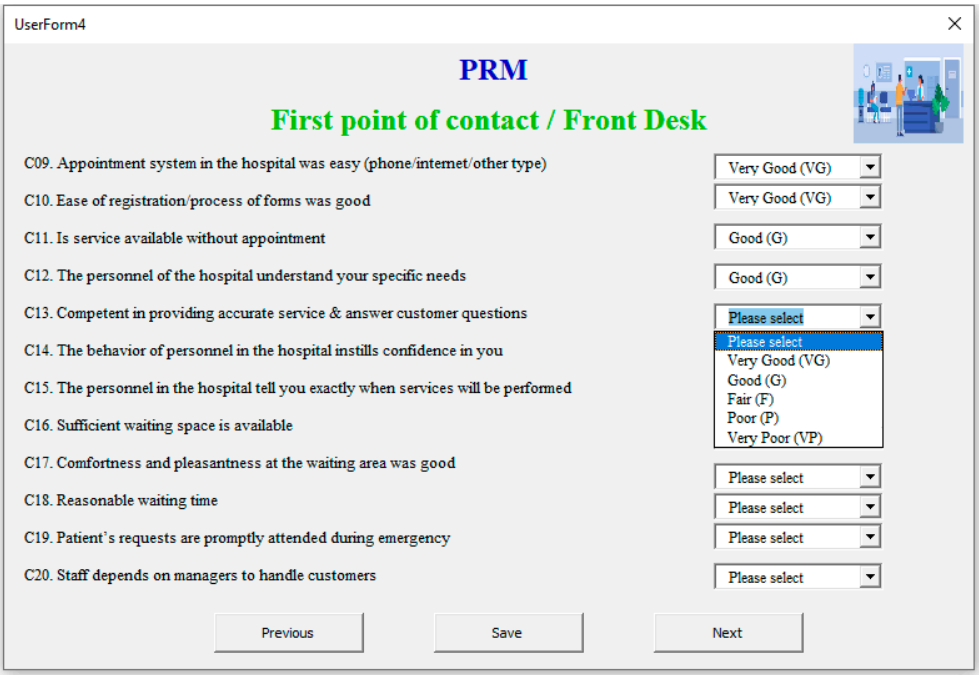


Figure 3. *Cont.*

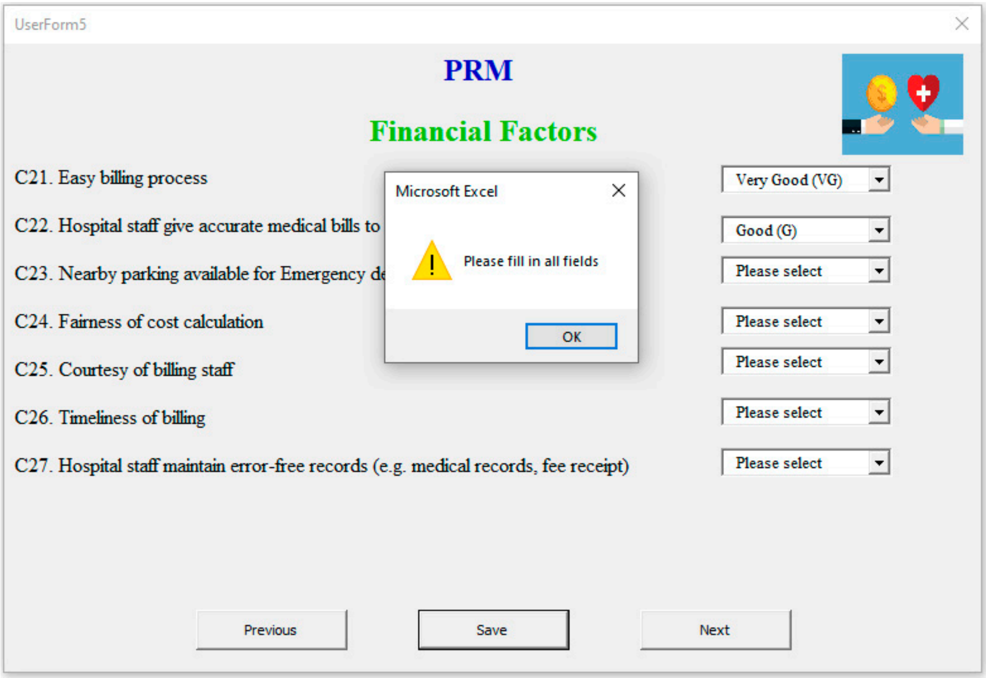


Figure 3. Screenshots of the data input interface.

3.5. Approach Adopted: Step-by-Step Illustration

An assessment method based on fuzzy logic was utilized to calculate the hospital service quality fuzzy index (HSQFI). The details are explained in the following subsection.

Step 1: Constructing a linguistic scale and the corresponding triangular fuzzy number to assess importance weights and performance ratings.

Hospital performance dimensions, factors, and criteria require the use of linguistic terminology for subject matter experts to assign performance ratings and importance weights. These terms are listed in Table 3 [51]. Assessors cannot reasonably determine the score of a vague criterion [50]; consequently, the performance ratings and importance weights of the service criteria were evaluated in this study using linguistic words. A score or evaluation of how effectively or successfully the hospital satisfies a specific dimension, factor, or criterion is known as the performance rating [52]. As shown in Table 3, the linguistic words and associated triangular fuzzy numbers were obtained from an earlier research work [55].

Table 3. Linguistic words and associated triangular fuzzy numbers for performance rating and importance.

Performance Rating (R)	Importance Weight (W)	Fuzzy Numbers
Very Poor (VP)	Very Low (VL)	(0, 0, 0.2)
Poor (P)	Low (L)	(0, 0.2, 0.4)
Fair (F)	Average (A)	(0.2, 0.4, 0.6)
Good (G)	High (H)	(0.4, 0.6, 0.8)
Very Good (VG)	Very High (VH)	(0.6, 0.8, 1)

Step 2: Collecting survey data for hospital service quality assessment.

Customers and health organization experts were given a survey to complete in order to evaluate the performance ratings and importance weights. They responded to a survey using linguistic words, which were subsequently converted to fuzzy numbers. Then, fuzzy arithmetic techniques were used to convert these fuzzy numbers into the corresponding fuzzy value, known as the hospital service quality fuzzy index (HSQFI) [53]. Responses collected from random customers and responses collected from the experts are presented in the following tabulated forms (refer Tables 4–7).

Table 4. Customer's response vs. service criteria.

		Customer's Response Matrix $R_k^n \rightarrow$		
		1	**2**	**n**
Service criteria $k \rightarrow$	1	R_1^1	R_1^2	R_n^1
	2	R_1^1	R_2^2	R_n^2
	k	R_k^1	R_k^2	R_k^n

Table 5. Expert's response vs. service criteria.

		Expert's Response e $\rightarrow$		
		1	**2**	**m**
Service criteria $k \rightarrow$	1	W_1^1	W_1^2	W_1^m
	2	W_2^1	W_2^2	W_2^m
	k	W_k^1	W_k^2	W_k^m

Table 6. Expert's response vs. service factors.

		Expert's Response e $\rightarrow$		
		1	**2**	**m**
Service factor $j \rightarrow$	1	W_1^1	W_1^2	W_1^m
	2	W_2^1	W_2^2	W_2^m
	j	W_j^1	W_j^2	W_j^m

Table 7. Expert's response vs. service dimensions.

		Expert's Response e $\rightarrow$		
		1	**2**	**m**
Service dimension $i \rightarrow$	1	W_1^1	W_1^2	W_1^m
	2	W_2^1	W_2^2	W_2^m
	i	W_i^1	W_2^1	W_i^m

Step 3: Combining fuzzy ratings and weights of service criterion k, service factor j, and service dimension i.

The linguistic terms used to describe the importance weights and performance ratings, R_n^k and W_m^k, as presented in the above matrix, were approximated with fuzzy numbers, which then had to be combined. For this, a variety of techniques, including computing the arithmetic mean, median, and mode, can be utilized. Here, the arithmetic mean approach was used. Where W_k^m and R_k^n reflect the service criterion's average importance weights and performance ratings, respectively. These numbers were calculated using Equations (1) and (2), as shown below [53,54].

$$R_k^{i,j} = \frac{\sum_1^n R_k^n}{n} \equiv \left(\frac{\sum_1^n a_k^n}{n}, \frac{\sum_1^n b_k^n}{n}, \frac{\sum_1^n c_k^n}{n}\right) \equiv \left(a_k^{i,j}, b_k^{i,j}, c_k^{i,j}\right) \tag{1}$$

$$W_k^{i,j} = \frac{\sum_1^m W_k^m}{m} \equiv \left(\frac{\sum_1^m x_k^m}{m}, \frac{\sum_1^m y_k^m}{m}, \frac{\sum_1^m z_k^m}{m}\right) \equiv \left(x_k^{i,j}, y_k^{i,j}, z_k^{i,j}\right) \tag{2}$$

In Equations (1) and (2),

$R_k^{i,j}$ is the overall performance rating for a particular set of service criteria (*k*) of factor (*j*) for a given service dimension (*i*).
$W_k^{i,j}$ is the overall importance weight for a particular set of service criteria (*k*) of factor (*j*) for a given service dimension (*i*).
R_k^n is the performance rating by a customer (1 to *n*) for a particular set of service criteria (*k*) of factor (*j*) for a given service dimension (*i*).
W_k^m is the importance weight assigned by an expert (1 to *m*) to a particular set of service criteria (*k*) of factor (*j*) for a given service dimension (*i*).

For R_k^n and W_k^m, refer to Tables 4 and 7.

(a_k^n, b_k^n, c_k^n) is the triangular fuzzy number that represents the performance rating by the customer for a particular service criterion (*k*) of factor (*j*) for a given service dimension (*i*).
(x_k^m, y_k^m, z_k^m) is the importance weight assigned by the expert to a particular service criterion (k) of factor (*j*) for a given service dimension (*i*).
$\left(a_k^{i,j}, b_k^{i,j}, c_k^{i,j}\right)$ is the triangular fuzzy number that represents the performance rating of service criterion (*k*) for factor (*j*) with respect to service dimension (*i*).
$\left(x_k^{i,j}, y_k^{i,j}, z_k^{i,j}\right)$ is the triangular fuzzy number that represents the average importance weight of service criterion (*k*) for factor (*j*) with respect to service dimension (*i*).

Similarly, Equation (3) was used to calculate the importance weight and corresponding triangular fuzzy number for hospital service factor (*j*) for a given service dimension (*i*), while Equation (4) was used to calculate the importance weight and corresponding triangular fuzzy number for hospital service dimension (*i*).

$$W_j^i = \frac{\sum_1^m W_j^m}{m} \equiv \left(\frac{\sum_1^m x_j^m}{m}, \frac{\sum_1^m y_j^m}{m}, \frac{\sum_1^m z_j^m}{m}\right) \equiv \left(x_j^i, y_j^i, z_j^i\right) \tag{3}$$

$$W_i = \frac{\sum_{e=1}^m W_i^m}{m} = \left(\frac{\sum_1^m x_i^m}{m}, \frac{\sum_1^m y_i^m}{m}, \frac{\sum_1^m z_i^m}{m}\right) \equiv (x_i, y_i, z_i) \tag{4}$$

In Equations (3) and (4),

W_j^m is the importance weight assigned by the expert to service factor (*j*) for a given service dimension (*i*), and $\left(x_j^m, y_j^m, z_j^m\right)$ is the corresponding triangular fuzzy number.
W_i^m is the importance weight assigned by the expert to service dimension (*i*) and (x_i^m, y_i^m, z_i^m) is the corresponding triangular fuzzy number.
W_j^i is the importance weight for service factor j for given service dimension (*i*), and $\left(x_j^i, y_j^i, z_j^i\right)$ is the corresponding triangular fuzzy number.
W_i is the importance weight assigned to service dimension (*i*), and (x_i, y_i, z_i) is the corresponding triangular fuzzy number.

Expert numbers vary from 1 to m, and customer counts vary from 1 to *n*.
Step 4: Calculate the hospital service quality fuzzy index (HSQFI).
The HSQFI represents the hospital service quality level of the health institution. The hospital service quality index was initially computed at the service factor level and after-

ward at the dimension level in order to estimate the HSQFI. Several service criteria are included in the hospital service quality index at the factor level, and all service factors are included in the hospital service quality index at the dimension level. The sub-steps below show the details.

Sub-Step 4.1: Calculate the hospital service quality index at the factor level.

Based on the fuzzy ratings and fuzzy weights of the hospital service criteria, the factor level estimation of the hospital service quality index (HSQI) was performed. The hospital service quality index was determined at the factor level using Equation (5) [54].

$$\mathrm{HSQI}_j^i \equiv \frac{\sum_k (\mathrm{R}_k^{i,j} * \mathrm{W}_k^{i,j})}{\sum_k \mathrm{W}_k^{i,j}} \equiv \left(\frac{\sum(\mathrm{a}_k^{i,j} * \mathrm{x}_k^{i,j})}{\sum_k \mathrm{x}_k^{i,j}}, \frac{\sum(\mathrm{b}_k^{i,j} * \mathrm{y}_k^{i,j})}{\sum_k \mathrm{y}_k^{i,j}}, \frac{\sum(\mathrm{c}_k^{i,j} * \mathrm{z}_k^{i,j})}{\sum_k \mathrm{z}_k^{i,j}} \right) \equiv \left(\mathrm{d}_j^{\mathrm{i}}, \mathrm{f}_j^{\mathrm{i}}, \mathrm{g}_j^{\mathrm{i}}\right) \quad (5)$$

In Equation (5),

HSQI_j^i is the hospital service quality index for service factor (j) for a specified service dimension (*i*).
$\mathrm{W}_k^{i,j}$ is the importance weight given by experts to service criterion (*k*) of service factor (*j*) for a specified service dimension (*i*), and $\left(\mathrm{x}_k^{i,j}, \mathrm{y}_k^{i,j}, \mathrm{z}_k^{i,j}\right)$ is its corresponding triangular fuzzy number.
$\mathrm{R}_k^{i,j}$ is the performance rating given by customers to service criterion (*k*) of service factor (*j*) for a specified service dimension (*i*), and $\left(\mathrm{a}_k^{i,j}, \mathrm{b}_k^{i,j}, \mathrm{c}_k^{i,j}\right)$ is its corresponding triangular fuzzy number.
$\left(\mathrm{d}_j^{\mathrm{i}}, \mathrm{f}_j^{\mathrm{i}}, \mathrm{g}_j^{\mathrm{i}}\right)$ is the estimated triangular fuzzy number for service factor (*j*) for a specified service dimension (*i*).

Sub-Step 4.2: Calculate hospital service quality index at dimension level.

The service quality index at the dimension level is calculated using the hospital service quality index at the factor level. Equation (6) is used to calculate the hospital service quality index (HSQI) at the dimension level [53].

$$\mathrm{HSQI}_i = \frac{\sum_j (\mathrm{HSQI}_j^i * \mathrm{W}_j^i)}{\sum_j \mathrm{W}_j^i} = \left(\frac{\sum_j (\mathrm{d}_j^{\mathrm{i}} * \mathrm{x}_j^{\mathrm{i}})}{\sum_j \mathrm{x}_j^{\mathrm{i}}}, \frac{\sum_j (\mathrm{f}_j^{\mathrm{i}} * \mathrm{y}_j^{\mathrm{i}})}{\sum_j \mathrm{y}_j^{\mathrm{i}}}, \frac{\sum_j (\mathrm{g}_j^{\mathrm{i}} * \mathrm{z}_j^{\mathrm{i}})}{\sum_j \mathrm{z}_j^{\mathrm{i}}} \right) \equiv (d_i, f_i, g_i) \quad (6)$$

In Equation (6),

HSQI_i is the hospital service quality index for a specified service dimension (*i*).
W_j^i is the importance weight for service factor (*j*) for a specified service dimension (*i*), and $\left(\mathrm{x}_j^{\mathrm{i}}, \mathrm{y}_j^{\mathrm{i}}, \mathrm{z}_j^{\mathrm{i}}\right)$ is the corresponding triangular fuzzy number.
(d_i, f_i, g_i) is the triangular fuzzy number representing hospital service quality for a specified service dimension (*i*). And the hospital service quality index for the i^{th} service dimension is HSQI_i.

Subsequently, using W_i (refer to Equation (4)) and HSQI_i (refer to Equation (6)) for each service dimension *i*, the hospital service quality fuzzy index (HSQFI) is calculated as presented in the following subsection.

Sub-Step 4.3: Determine the hospital service quality fuzzy index (HSQFI).

To calculate the hospital service quality fuzzy index (HSQFI), use Equation (7) [56]:

$$\mathrm{HSQFI} \equiv \frac{\sum_i (\mathrm{HSQI}_i * \mathrm{W}_i)}{\sum_i \mathrm{W}_i} \equiv \left(\frac{\sum_i (d_i * x_i)}{\sum_i x_i}, \frac{\sum_j (f_i * y_i)}{\sum_i y_i}, \frac{\sum_i (g_i * z_i)}{\sum_i z_i} \right) \equiv (\mathrm{h}, \mathrm{o}, \mathrm{p}) \quad (7)$$

In Equation (7), W_i is the importance weight for service dimension (*i*), and (x_i, y_i, z_i) is its associated fuzzy number. HSQI_i is the hospital service quality index for service dimension (*i*) and (d_i, f_i, g_i) is its associated fuzzy number.

HSQFI is the overall hospital service quality fuzzy index and (h, o, p) is its associated triangular fuzzy number. A scheme to facilitate the understanding of Equations (1)–(7) is presented in Figure 4.

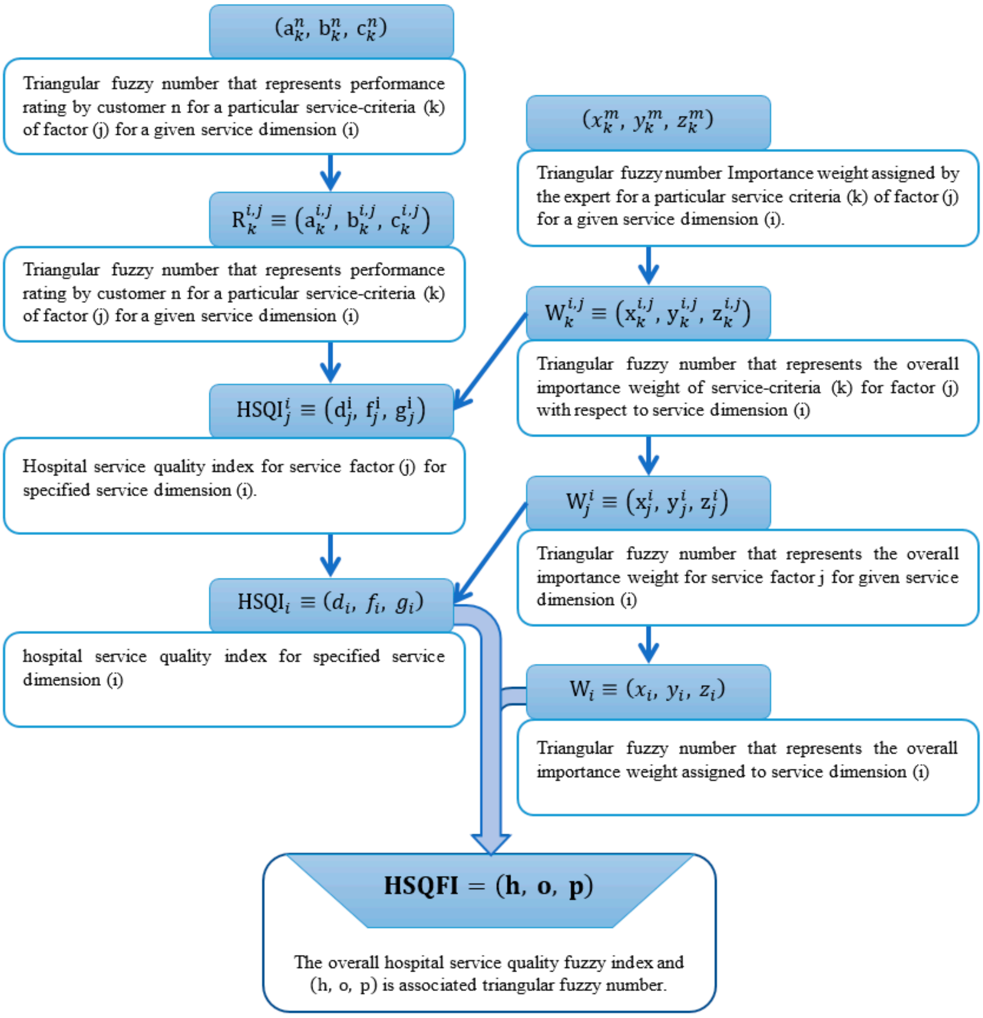


Figure 4. A scheme to estimate the hospital service quality fuzzy index.

The next goal is to describe the total hospital service quality in language terms and to pinpoint any obstacles that may prevent this target from being achieved. This is accomplished as shown in the subsection that follows.

Step 5: Estimate the Euclidean distance required to match the HSQFI with the closest service level.

Table 8 [53] presents information on how to defuzzify the hospital service quality fuzzy index (HSQFI) after it has been calculated. The Euclidean distance approach was used in this instance since it is one of the most reasonable methods for determining proximity [49].

Table 8. Expressions set in natural language for designating the level of service quality.

Linguistic Variable	Service Level (Level r)	Fuzzy Numbers (q_r, f_r, v_r)		
		q_r	f_r	v_r
Very Good Service	5	0.7	0.85	1
Good Service	4	0.55	0.7	0.85
Average Service	3	0.35	0.5	0.65
Fair Service	2	0.15	0.3	0.45
Poor Service	1	0	0.15	0.3

Table 8 displays five service quality levels (r = 1 to 5) along with their related five linguistic words. The relevant service quality fuzzy numbers for each level r are denoted by the variables (q_r, f_r, v_r). Equation (8) can be used to find the Euclidean distance D between HSQFI and hospital service quality level using the Euclidean distance approach [54].

$$D(HSFQI,\ HSQL_r)\ \equiv D((h,\ o,\ p),\ (q_r,\ f_r,\ v_r))\ \equiv \left\{(h-q_r)^2+(h-f_r)^2+(h-v_r)^2\right\}^{1/2} \quad (8)$$

Step 6: Identify barriers to improve hospital service quality levels.

Improving a health organization's service quality requires identifying and evaluating service barriers. These obstacles will affect the level of service quality. The goal is to achieve the top level (r = 5), the highest attainable level. These kinds of barriers can be found using the criteria performance index (CPI; see Equation (9)) [53,54].

$$\mathrm{CPI}_k^{i,j} \equiv \left(1-\mathrm{W}_k^{i,j}\right)\ \times\ \mathrm{R}_k^{i,j} \equiv (\Theta, \varnothing, \Psi) \quad (9)$$

Thus, for all k service criteria, the CPI is calculated. However, ranking the CPIs is necessary since, unlike real numbers, fuzzy numbers do not always result in an ordered set [51]. The literature has numerous methods for ranking fuzzy numbers. Because the centroid technique is straightforward and simple to use, it is employed in this study to rank the CPIs. Each service criterion is then rated in accordance with its ranking score, which is determined using Equation (10). Hence, as a result, a threshold value must be determined in order to pinpoint obstacles to offering the best service. The threshold value is computed using Equation (11), as shown below.

$$\text{Criteria Ranking score} = \left(\frac{\Theta+4\varnothing+\Psi}{6}\right) \quad (10)$$

$$\textit{The threshold value} = \left(\frac{\text{Median}+4*\text{Min}+\text{Max}}{6}\right) \quad (11)$$

The hospital service criteria fuzzy ranking score is compared to the threshold value for any given health institution, which serves as a benchmark. Service criteria whose performance falls short of the threshold value are listed and can be recognized as barriers to the quality of hospital services. In order to improve the service criteria's weaker areas, these barriers must be attended to, which in turn will enhance the overall hospital service quality levels. In the section that follows, the method for assessing service quality mentioned above was applied to determine the degree of service quality in a hospital in Riyadh, Saudi Arabia.

4. Case Study: An Illustrative Example

Since the management of the Saudi Arabian hospital did not agree to disclose its identity, it is referred to as "XYZ". Below is a step-by-step process for evaluating the quality of service at the case organization.

Step 1: Constructing a linguistic scale and the corresponding fuzzy number to assess importance weights and performance ratings.

As shown in Table 3, the linguistic words and associated fuzzy numbers were obtained from a prior study [51].

Step 2: Collecting survey data for hospital service quality assessment.

Customers visited various service areas in the hospital, and there, the visiting customers were asked randomly to rate each criterion using linguistic terms. Six hundred customer responses were collected and all of them were adopted in the study. A sample of responses from the first five customers is presented in Table 9. Similarly, selected experts were asked to weight the service quality dimensions, factors, and criteria. Fifteen experts were selected, and a sample of responses from the experts is presented in Tables 10–12.

Table 9. Sample customers' performance ratings for each service criterion k: (R_n^k).

n [$] →	1	2	3	4	5	n →	1	2	3	4	5	n →	1	2	3	4	5
k [*]↓	$\mathbf{R}_1^k$	$\mathbf{R}_2^k$	$\mathbf{R}_3^k$	$\mathbf{R}_4^k$	$\mathbf{R}_5^k$	k [*]↓	$\mathbf{R}_1^k$	$\mathbf{R}_2^k$	$\mathbf{R}_3^k$	$\mathbf{R}_4^k$	$\mathbf{R}_5^k$	k [*]↓	$\mathbf{R}_1^k$	$\mathbf{R}_2^k$	$\mathbf{R}_3^k$	$\mathbf{R}_4^k$	$\mathbf{R}_5^k$
C01 [@]	VG [#]	G	VG	VG	VG	**C27**	VG	VG	VG	VG	VG	**C53**	G	F	F	G	F
C02	F	P	P	F	P	**C28**	F	P	F	F	P	**C54**	VG	G	G	VG	VG
C03	P	VP	P	VP	P	**C29**	P	VP	P	P	VP	**C55**	G	VG	G	VG	VG
C04	P	VP	VP	P	P	**C30**	P	F	F	P	F	**C56**	VG	VG	VG	G	VG
C05	VG	G	VG	VG	G	**C31**	VG	VG	G	VG	VG	**C57**	VG	VG	VG	VG	VG
C06	VG	VG	VG	VG	VG	**C32**	VG	VG	VG	G	VG	**C58**	VG	VG	VG	VG	VG
C07	G	VG	G	VG	G	**C33**	G	VG	G	G	VG	**C59**	VG	VG	VG	VG	G
C08	F	G	F	P	F	**C34**	G	VG	VG	G	G	**C60**	F	P	F	F	P
C09	F	F	F	P	G	**C35**	VG	VG	G	VG	VG	**C61**	F	G	F	F	G
C10	G	F	G	F	F	**C36**	VG	F	G	F	VG	**C62**	VG	VG	G	VG	VG
C11	P	VP	VP	P	P	**C37**	VG	G	VG	VG	G	**C63**	VG	G	G	VG	VG
C12	G	F	F	G	VG	**C38**	VG	VG	G	VG	VG	**C64**	VG	VG	VG	VG	VG
C13	F	P	G	F	P	**C39**	G	F	G	F	VG	**C65**	G	VG	VG	VG	VG
C14	F	G	F	P	G	**C40**	G	VG	G	VG	VG	**C66**	G	F	G	F	G
C15	P	P	G	F	F	**C41**	F	F	P	F	F	**C67**	F	P	P	G	F
C16	VG	G	G	VG	G	**C42**	VG	G	VG	G	VG	**C68**	P	F	F	P	F
C17	VG	G	VG	VG	G	**C43**	VG	G	G	VG	G	**C69**	F	P	G	F	G
C18	F	P	F	P	F	**C44**	VG	G	F	F	VG	**C70**	G	VG	F	G	G
C19	F	P	VP	G	F	**C45**	G	VG	F	G	VG	**C71**	P	F	F	P	VG
C20	VG	G	F	F	F	**C46**	P	F	P	P	P	**C72**	F	P	F	VG	G
C21	VG	VG	VG	VG	VG	**C47**	VG	VG	VG	VG	VG	**C73**	F	G	F	F	G
C22	VG	VG	VG	VG	VG	**C48**	G	VG	G	VG	G	**C74**	G	VG	G	G	F
C23	VG	VG	VG	VG	VG	**C49**	VG	VG	G	VG	G	**C75**	G	VG	VG	G	VG
C24	VG	VG	VG	VG	VG	**C50**	VG	VG	VG	VG	VG	**C76**	F	P	F	VG	VG
C25	VG	VG	VG	VG	VG	**C51**	VG	VG	VG	VG	VG	**C77**	F	F	G	VG	VG
C26	VG	VG	VG	VG	VG	**C52**	VG	VG	VG	VG	VG	**C78**	F	F	G	VG	VG

Notes: *, #, $, and @ refer to Table 2; R_1^k is the performance rating by customer 1 for service criterion k related to factor j with respect to dimension i.

Table 10. Importance of the expert-assigned weighting to each service criterion k: (W_m^k).

m [$] →	1	2	3	4	5	m →	1	2	3	4	5	m →	1	2	3	4	5
k [*]↓	$\mathbf{W}_1^k$	$\mathbf{W}_2^k$	$\mathbf{W}_3^k$	$\mathbf{W}_4^k$	$\mathbf{W}_5^k$	k [*]↓	$\mathbf{W}_1^k$	$\mathbf{W}_2^k$	$\mathbf{W}_3^k$	$\mathbf{W}_4^k$	$\mathbf{W}_5^k$	k [*]↓	$\mathbf{W}_1^k$	$\mathbf{W}_2^k$	$\mathbf{W}_3^k$	$\mathbf{W}_4^k$	$\mathbf{W}_5^k$
C01 [@]	H [#]	H	H	VH	VH	**C27**	VH	VH	H	VH	VH	**C53**	A	VH	VH	VH	H
C02	H	A	H	A	H	**C28**	VH	A	VH	H	H	**C54**	H	H	A	VH	A
C03	A	A	A	A	H	**C29**	VH	H	VH	H	A	**C55**	H	VH	VH	H	H
C04	H	A	H	A	H	**C30**	VH	VH	VH	H	VH	**C56**	VH	A	VH	H	VH
C05	VH	A	VH	VH	H	**C31**	VH	VH	VH	VH	VH	**C57**	H	VH	VH	VH	VH
C06	VH	H	H	VH	VH	**C32**	VH	VH	VH	VH	VH	**C58**	VH	H	H	VH	VH
C07	A	H	VH	VH	A	**C33**	VH	VH	VH	VH	VH	**C59**	VH	H	H	H	H
C08	H	A	H	VH	H	**C34**	H	VH	H	VH	A	**C60**	H	VH	VH	L	L
C09	A	A	VH	H	VH	**C35**	A	H	A	H	A	**C61**	VH	VH	VH	A	H
C10	H	H	H	H	H	**C36**	H	VH	VH	H	H	**C62**	VH	VH	VH	VH	H
C11	A	L	A	L	VH	**C37**	VH	H	VH	VH	VH	**C63**	A	H	H	A	A
C12	A	A	A	H	H	**C38**	A	VH	A	H	H	**C64**	A	H	VH	L	A
C13	A	A	A	A	VH	**C39**	VH	VH	A	H	A	**C65**	A	H	A	H	A
C14	A	A	VH	A	VH	**C40**	VH	H	VH	VH	H	**C66**	H	A	A	H	A
C15	A	A	H	H	L	**C41**	H	VH	H	H	VH	**C67**	H	A	A	A	H
C16	H	H	VH	H	VH	**C42**	A	VH	H	H	VH	**C68**	A	H	VH	A	A
C17	VH	H	H	H	VH	**C43**	A	H	A	H	H	**C69**	H	VH	H	H	H
C18	A	VH	A	A	VH	**C44**	H	A	A	VH	VH	**C70**	A	VH	VH	H	H
C19	H	H	H	H	H	**C45**	H	H	A	A	VH	**C71**	H	H	H	H	H
C20	L	A	L	L	H	**C46**	VH	H	A	VH	A	**C72**	VH	A	H	H	H
C21	VH	VH	H	VH	VH	**C47**	VH	H	H	VH	VH	**C73**	H	VH	VH	H	H
C22	VH	A	H	VH	H	**C48**	A	VH	VH	VH	A	**C74**	H	VH	VH	A	VH
C23	VH	H	H	VH	VH	**C49**	A	H	A	H	H	**C75**	VH	H	VH	VH	VH
C24	H	A	L	H	H	**C50**	VH	VH	VH	VH	VH	**C76**	H	VH	H	A	H
C25	H	A	A	VH	VH	**C51**	VH	VH	VH	VH	VH	**C77**	VH	VH	H	VH	H
C26	H	H	A	A	H	**C52**	VH	H	VH	VH	H	**C78**	VH	VH	VH	VH	VH

Notes: *, #, $, and @ please see Table 2; (W_1^k) is the importance of the expert 1-assigned weighting for service criterion k.

Table 11. Importance weighting assigned by expert to each service factor *j*: (W_m^j).

m [$] →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
j * ↓	W_1^j	W_2^j	W_3^j	W_4^j	W_5^j	W_6^j	W_7^j	W_8^j	W_9^j	W_{10}^j	W_{11}^j	W_{12}^j	W_{13}^j	W_{14}^j	W_{15}^j
F01 [@]	H [#]	A	H	A	H	H	H	A	H	H	H	VH	A	H	H
F02	A	A	H	A	H	A	A	H	A	A	A	H	H	H	H
F03	VH	H	A	VH	VH	H	VH	VH	H	VH	H	H	VH	H	VH
F04	VH	VH	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH
F05	H	H	A	H	H	VH	VH	VH	VH	H	VH	H	H	VH	VH
F06	H	VH	H	H	H	VH	H	H	H	H	H	H	VH	VH	H
F07	A	H	H	A	A	H	H	H	H	H	H	H	H	H	H
F08	VH	VH	VH	H	H	VH	H	VH	VH	VH	H	VH	VH	H	VH

Notes: *, #, $, and @ refer to Table 2; (W_1^j) is the importance of the expert 1-assigned weighting for service factor *j*.

Table 12. Importance weighting assigned by expert to each service dimension *i* (W_m^i).

m [$] →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
i * ↓	W_1^i	W_2^i	W_3^i	W_4^i	W_5^i	W_6^i	W_7^i	W_8^i	W_9^i	W_{10}^i	W_{11}^i	W_{12}^i	W_{13}^i	W_{14}^i	W_{15}^i
D01 [@]	H [#]	H	H	H	H	VH	H	H	H	H	H	H	VH	H	H
D02	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH
D03	H	H	VH	H	VH	H	H	H	VH	VH	H	H	H	VH	H

Notes: *, #, $, and @ refer to Table 2; W_{i1} is the importance of the expert 1-assigned weighting to service dimension *i*.

In Tables 3–10, for example, customer 1 (refer to Table 3) responded to the survey that service criterion C01 (i.e., hospital is conveniently located to get medical aid whenever the patient needs) had a very good (VG) performance rating, while for the same service criterion (refer to Table 4) expert 1 assigned a high (H) importance weight, and expert 4 assigned a very high (VH) importance to location, i.e., C01. Whereas Tables 9 and 10 highlight the responses from fifteen experts to each of the service areas (factors) and service dimensions affecting the hospital service quality, respectively. From Table 11 it is evident that the majority of experts are of the opinion that accessibility and arrival factor (F01) have a high contribution in improving hospital service quality, while few experts are of the opinion that this factor has an average contribution in improving hospital service quality. Similarly, for medical consultation/treatment factor (F04), almost all experts are of the opinion that this factor (F04) has a very high contribution to improving hospital service quality; a majority of experts also set high importance on financial factor (F03) as well as customer satisfaction and loyalty (F08). While the lowest and average weightings are evident for the first point of contact factor or front desk factor (F02). Lastly, from Table 6 it is obvious that experts and management prefer to assign very high importance to all service dimensions D01 to D03.

Step 3: Combining fuzzy ratings and weights of service criterion k, service factor j, and service dimension i.

The fuzzy performance rating and importance weight calculations for the PPR dimension D02 (i = 2), medical consultation/treatment factor F04 (j = 4), and service criterion "time it took to meet doctor" C28 (k = 28) for the case organization are presented below as an example. The fuzzy performance rating (R_{29}^c) and fuzzy importance weight (W_{28}^c) for all customers' and experts' responses to service criterion k = 28 are calculated using sample information from Tables 9 and 10 and Equations (1) and (2). Similarly, the fuzzy importance weight $W_{j=4}^{i=2}$ (for PPR dimension D02 (i = 2) and medical consultation/treatment service factor F04 (j = 4)) is estimated using Equation (3) and Table 5. The details are shown below. The importance weights and performance ratings that were determined for each service criterion (k = 28 to 37) with respect to medical consultation/treatment factor F04

(j = 4), and triangular fuzzy importance weight $W_j^{i=2}$ for dimension D02 (i = 2), medical consultation/treatment factor F04 (j = 4), are presented in Table 13.

$$R_{k=28}^{i=2,j=4} = R_{28}^{2,4} \equiv \frac{\sum_1^n R_{28}^n}{n} \equiv \left(\frac{F+P+F+F+P+\ldots+\ldots+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}{n} \right)$$

$$R_{28}^{2,4} \equiv \left(\frac{(0.2,0.4,0.6)+(0.0,0.2,0.4)+(0.2,0.4,0.6)+(0.2,0.4,0.6)+(0.0,0.2,0.4)+\ldots\ldots\ldots\ldots}{n} \right)$$

$$R_{28}^{2,4} \equiv \left(\frac{(0.2+0.0+0.2+0.2+0.0+\ldots\ldots\ldots\ldots\ldots)}{n}, \frac{(0.4+0.2+0.4+0.4+0.2+\ldots\ldots\ldots\ldots)}{n}, \frac{(0.6+0.4+0.6+0.6+0.4+\ldots\ldots\ldots\ldots)}{n} \right)$$

$$R_{28}^{2,4} \equiv (0.27, 0.47, 0.67) \equiv \left(a_{28}^{2,4}, b_{28}^{2,4}, c_{28}^{2,4} \right)$$

$$W_{28}^{2,4} \equiv \frac{\sum_1^m W_{29}^m}{m} \equiv \left(\frac{VH+A+VH+H+H+A+H+VH+H+H+VH+VH+VH+VH+VH}{15} \right)$$

$$W_{k=28}^{i=2,j=4} = W_{28}^{2,4} \equiv \left(\frac{\begin{array}{c}(0.6,0.8,1.0)+(0.2,0.4,0.6)+(0.6,0.8,1.0)+(0.4,0.6,0.8)+(0.4,0.6,0.8)+\\(0.2,0.4,0.6)+(0.4,0.6,0.8)+(0.6,0.8,1.0)+(0.4,0.6,0.8)+(0.4,0.6,0.8)+\\(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)\end{array}}{15} \right)$$

$$W_{28}^{2,4} \equiv (0.48, 0.68, 0.88) \equiv \left(x_{28}^{2,4}, y_{28}^{2,4}, z_{28}^{2,4} \right)$$

$$W_{j=4}^{i=2} = W_4^2 \equiv \frac{\sum_1^m W_4^m}{m} \equiv \left(\frac{VH+VH+VH+VH+H+VH+VH+VH+VH+VH+VH+VH+VH+VH+VH}{m} \right)$$

$$W_4^2 \equiv \left(\frac{\begin{array}{c}(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.4,0.6,0.8)+\\(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+\\(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)+(0.6,0.8,1.0)\end{array}}{15} \right)$$

Table 13. Triangular fuzzy performance ratings and importance weights for all criteria with respect to medical consultation/treatment factor F04 (j = 4) with respect to hospital service quality dimension D02 (i =2).

$W_j^i \equiv \left(x_j^i, y_j^i, z_j^i\right)$ **Factor Weight**	$W_k^{i,j} \equiv \left(x_k^{i,j}, y_k^{i,j}, z_k^{i,j}\right)$ **Criterion Weight**	$R_k^{i,j} \equiv \left(a_k^{i,j}, b_k^{i,j}, c_k^{i,j}\right)$ **Criterion Performance**	**Service Criterion (*k*)**	**Service Criterion Code**
Medical consultation/ treatment factor F04 # $W_{j=4}^{i=2} \equiv (0.59, 0.79, 0.99) \equiv \left(x_4^2, y_4^2, z_4^2\right)$	(0.48, 0.68, 0.88)	(0.27, 0.47, 0.67)	28 #	C28 #
	(0.47, 0.67, 0.87)	(0.2, 0.37, 0.57)	29	C29
	(0.56, 0.76, 0.96)	(0.21, 0.41, 0.61)	30	C30
	(0.60, 0.80, 1.00)	(0.54, 0.74, 0.94)	31	C31
	(0.60, 0.80, 1.00)	(0.55, 0.75, 0.95)	32	C32
	(0.49, 0.69, 0.89)	(0.44, 0.64, 0.84)	33	C33
	(0.45, 0.65, 0.85)	(0.47, 0.67, 0.87)	34	C34
	(0.41, 0.61, 0.81)	(0.43, 0.63, 0.83)	35	C35
	(0.48, 0.68, 0.88)	(0.35, 0.55, 0.75)	36	C36
	(0.49, 0.69, 0.89)	(0.52, 0.72, 0.92)	37	C37

Notes: # refer to Table 2; W_j^i is the importance weighting assigned by the set of experts to service factor j for a given service dimension i; $W_k^{i,j}$ is the importance weighting assigned by the set of experts to service criterion k for a given service factor j and dimension i; and $R_k^{i,j}$ is the preference ranking assigned by customers to service criterion k for a given service factor j and dimension i.

In Table 13, the importance weight for the medical consultation/treatment service area as factor F04 is (0.59, 0.79, 0.99), which falls into the very high importance weight level 5 linguistic terms according to the fuzzy numbers (refer to Table 3). The service criterion 'time it took to meet doctor' C28 (k = 28), assigned a high importance weighting of (0.48, 0.68, 0.88), can be interpreted as meaning that the service area needs to have a minimum time to wait for a doctor. In response to this, the overall customer performance rating is observed to be average, i.e., (0.27, 0.47, 0.67), which means the health organization needs to reduce its waiting time to see a doctor. At the same time, both service criteria "physician knowledge and adequate treatment protocol" C32 and "patients' safety under physicians while treatment" C37 scored very highly in the performance rating. The organization is, thus, doing well with regard to the skills of its physicians, and their knowledge, treatment methodologies, and safety protocols. Whereas waiting time to meet doctor (C28), physician availability as need medical services arises (C29), and nursing staff availability (C36) are the service criteria with average performance that need attention.

Similarly, the importance weighting W_i for service dimension i is estimated. As illustrated, the fuzzy importance weighting W_1 in response to service factors F01 (j = 1) and F06 (j = 6) is calculated using sample information from Table 12 and Equation (4), and is presented below. Subsequently, the calculated importance weights for all service dimensions (i = D01 to D03) are also presented in Table 14.

$$W_{i=1} = W_1 \equiv \frac{\sum_1^{m=15} W_1^m}{m} \equiv \left(\frac{H+H+H+H+H+H+VH+H+H+H+H+H+H+VH+H+H}{m}\right)$$

$$W_1 \equiv \left(\frac{\begin{array}{c}(0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + \\ (0.6, 0.8, 1.0) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + \\ (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8) + (0.6, 0.8, 1.0) + (0.4, 0.6, 0.8) + (0.4, 0.6, 0.8)\end{array}}{15}\right)$$

$$W_1 \equiv (0.43, 0.63, 0.83) \equiv (x_1, y_1, z_1)$$

Table 14. Triangular fuzzy importance weightings for all service dimensions.

Service Dimension (i)	Service Dimension Code	$\mathbf{W}_i \equiv (\mathbf{x}_i, \mathbf{y}_i, \mathbf{z}_i)$
1 #	PMS: D01 #	(0.43,0.63,0.83)
2	PPR: D02	(0.60,0.80,1.00)
3	PMR: D03	(0.47,0.67,0.87)

Notes: # Refer to Table 2; W_i is the importance weighting assigned by the set of experts to service dimension i.

The importance weights for the PMS service dimension D01 and PMR service dimension D03 in Table 14 have high importance weights, level 4, in terms of the linguistic terms based on fuzzy numbers (see Table 3); whereas PPR service dimension D02 falls into the very high importance weights, level 5.

Step 4: Calculate the hospital service quality fuzzy index (HSQFI).

Prior to computing the HSQFI, the HSQI was first computed at the factor level j and then at the dimension level i. Numerous service-related criteria k are included in HSQI in the factor j, and all service-related factors j are included in the HSQI in the dimension i. Below, the sub-steps are an explanation of the calculation of the hospital service quality fuzzy index for the case study.

Sub-Step 4.1: Calculate the hospital service quality index for factor j.

For instance, the hospital service quality index calculation for the case organization HSQI_j^i for "PPR" dimension D02 (i = 2), service factor 'medical consultation/treatment factors' F04 (j = 4), HSQI_4^2 is estimated using Equation (5) and values from Table 13, and is determined as follows:

$$\mathrm{HSQI}_4^2 = \begin{bmatrix} \frac{(0.27*0.48+0.2*0.47+0.21*0.56+0.54*0.60+0.55*0.60+ \\ 0.44*0.49+0.47*0.45+0.43*0.41+0.35*0.48+0.52*0.49)}{(0.48+0.47+0.56+0.60+0.60+0.49+0.45+0.41+0.48+0.49)}, \\ \frac{(0.47*0.68+0.37*0.67+0.41*0.76+0.74*0.80+0.75*0.80+ \\ 0.64*0.69+0.67*0.65+0.63*0.61+0.55*0.68+0.72*0.69)}{(0.68+0.67+0.76+0.80+0.80+0.69+0.65+0.61+0.68+0.69)}, \\ \frac{(0.67*0.88+0.57*0.87+0.61*0.96+0.94*1.00+0.95*1.00+ \\ 0.84*0.89+0.87*0.85+0.83*0.81+0.75*0.88+0.92*0.89)}{(0.88+0.87+0.96+1.00+1.00+0.89+0.85+0.81+0.88+0.89)} \end{bmatrix} \equiv (0.402, 0.598, 0.797) \equiv \left(\mathrm{d}_4^2, \mathrm{f}_4^2, \mathrm{g}_4^2\right)$$

Thus, as illustrated above using above Equations (1)–(5) and information in Tables 9–14, the hospital service quality index HSQI_j^i for each service factor j is calculated and presented in Table 15.

Table 15. Triangular fuzzy importance weight and hospital service quality index for each service factor.

i	Service Dimension	j	Service Factors	$\mathbf{W}_j^i \equiv \left(x_j^i, y_j^i, z_j^i\right)$	$\mathbf{HSQI}_j^i \equiv \left(d_j^i, f_j^i, g_j^i\right)$
1	# D01: PMS	1	# F01: Accessibility and arrival factors	(0.360, 0.560, 0.760)	(0.330, 0.503, 0.698)
3	D03: PPR	2	F02: First point of contact factors/front desk factors	(0.293, 0.493, 0.693)	(0.307, 0.500, 0.698)
3	D03: PPR	3	F03: Financial factors	(0.493, 0.693, 0.893)	(0.553, 0.753, 0.953)
2	D02: PRM	4	F04: Medical consultation/treatment factors	(0.587, 0.787, 0.987)	(0.402, 0.598, 0.797)
2	D02: PRM	5	F05: Post-consultation/treatment factors	(0.480, 0.680, 0.880)	(0.419, 0.618, 0.818)
1	D01: PMS	6	F06: Medical support/Other services factors	(0.453, 0.653, 0.853)	(0.483, 0.682, 0.881)
3	D03: PPR	7	F07: Appearance and behavior (staff and facilities)	(0.360, 0.560, 0.760)	(0.386, 0.588, 0.789)
3	D03: PPR	8	F08: Customer satisfaction and loyalty	(0.533, 0.733, 0.933)	(0.352, 0.551, 0.751)

Notes: # Refer to Table 2; W_j^i is the importance weighting assigned by the set of experts to service-factor j for a given service dimension i; HSQI_j^i is the hospital service quality index for a given service factor j and dimension i.

Table 14 shows that the hospital service factors "F01" and "F02" had the lowest index values and indicate very fair performance in accessibility and arrival and first point of contact, i.e., front desk. Therefore, the organization should focus on these criteria to enhance its service index. Whereas, it is also evident that service factor F04, related to the finance department, has the highest index value. This shows that from a financial management point of view, customers are highly satisfied with the hospital management. Also, comparing the last two columns of Table 15, it is clear that almost all service factors and dimensions weightings and index values are close to each other; except for the factor 'customer satisfaction and loyalty', management is giving very high importance to these criteria, but its performance index is at a fair level. So, addressing this factor is also an important task in future plans of action.

Sub-Step 4.2: Calculate hospital service quality index at dimension level.

By means of the HSQI_j^i service quality index at the service factor level, an estimation of hospital service quality index at the dimension level (HSQI_i) is performed. The HSQI_i at dimension level is calculated by using Equation (6) [53] and is presented in Table 16.

$$\mathrm{HSQI}_i \equiv \begin{bmatrix} \frac{(0.330\times0.360+0.483\mathrm{x}0.453)}{(0.360+0.453)}, \\ \frac{(0.503\mathrm{x}0.560+0.682\mathrm{x}0.653)}{(0.560+0.653)}, \\ \frac{(0.698\mathrm{x}0.760+0.881\mathrm{x}0.853)}{(0.760+0.853)} \end{bmatrix} \equiv (0.416, 0.599, 0.795) \equiv (\mathrm{d}_i, \mathrm{f}_i, \mathrm{g}_i)$$

Table 16. Hospital service quality index for each service dimension *i*.

Service Dimension (i)	Service Dimension Code	$W_i \equiv (x_i, y_i, z_i)$	$HSQI_i \equiv (d_i, f_i, g_i)$
1 #	PMS: D01 #	(0.43, 0.63, 0.83)	(0.416, 0.599, 0.795)
2	PPR: D02	(0.60, 0.80, 1.00)	(0.410, 0.607, 0.807)
3	PMR: D03	(0.47, 0.67, 0.87)	(0.411, 0.606, 0.803)

Notes: # refer to Table 2; W_i is the importance weighting triangular fuzzy number to service dimension *i*; and $HSQI_i$ the estimated hospital service quality index for dimension *i*.

From Table 16, it is evident that the hospital service quality index for all three service dimensions falls into the good level of performance level 4, as per the linguistic terms according to the fuzzy numbers (refer to Table 3); whereas for PPR service dimension D02, it falls into the very high importance weight, level 5.

Sub-Step 4.3: Determine overall hospital service quality fuzzy index (HSQFI)

Thus, for the health organization, the HSQFI represents the overall service performance. This number is the final score used to define the service quality achieved by the hospital or the hospital's final rating compared to a benchmark with a competitor. This index is calculated using Equation (7) and Table 16. From the estimated HSQFI, it is clear that the case-studied hospital is performing well, at service level 4; still, there is scope to achieve service level 5. To target this, management wishes to prioritize the service criteria to be focused on.

$$\text{HSQFI} \equiv \begin{bmatrix} \frac{0.430*0.416+0.600*0.410+0.470*0.411}{0.430+0.600+0.470}, \\ \frac{0.630*0.599+0.800*0.607+0.670*0.606}{0.630+0.800+0.670}, \\ \frac{0.830*0.795+1.000*0.807+0.870*0.803}{0.830+1.000+0.870} \end{bmatrix} \equiv (0.412, 0.604, 0.802) \equiv (\text{h}, \text{o}, \text{p})$$

Step 5: Estimate the Euclidean distance required to match the HSQFI with the closest service level.

Using the aforementioned Equation (8), the shortest Euclidean distance between the HSQFI and HSQL was identified between five computed distances, as shown in Tables 17 and 18. For the studied case, on hand, the HSQFI is (h, o, p) ≡ (0.412, 0.604, 0.802) and HSQL_r, where level r = 5, HSQL_5 ≡ (very good service level, (q_5, f_5, v_5) ≡ (0.700, 0.850, 1.000)) for the hospital; the Euclidean distance (D) was calculated for r = 5. Similar calculations are made for the other Euclidean distances for the service quality level (for r = 1 to 5), and the results are shown in Table 18.

$$D((0.412, 0.604, 0.802), (0.700, 0.850, 1.000)) \equiv \left\{(0.412-0.700)^2 + (0.604-0.850)^2 + (0.802-1.000)^2\right\}^{\frac{1}{2}} = 0.427$$

Table 17. Natural language expression set for labeling the service quality level.

Linguistic Variable	Service Level (Level r)	Fuzzy Numbers (q_r, f_r, v_r)		
		q_r	f_r	v_r
Very Good Service	5	0.700	0.850	1.000
Good Service	4	0.550	0.700	0.850
Average Service	3	0.350	0.500	0.650
Fair Service	2	0.150	0.300	0.450
Poor Service	1	0	0.15	0.300

The minimum distance of hospital service quality level r is represented by D (HSQFI, HSQL_r); in the present case, the minimum distance is 0.175 for service quality level 4. As a result, the health organization has attained a high degree of service quality. For this reason, the case organization's HSQFI fuzzy index level is evaluated as "highly serviceable", as demonstrated in Figure 5 below, which matches a linguistic label with the least Euclidean distance.

Table 18. Euclidean distance to match HSQFI with all service quality levels.

Service Quality Level	r	Euclidean Distance D
Extremely Good Service Quality	5	0.427
Good Service Quality	4	0.175
Average Service Quality	3	0.194
Fair Service Quality	2	0.534
Poor Service Quality	1	0.792

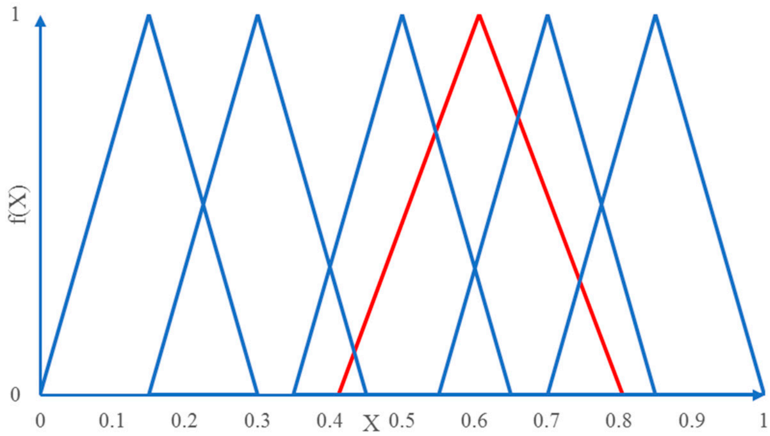


Figure 5. Linguistic levels for matching HSQFI.

Step 6: Identify barriers to improve hospital service quality levels

The health organization's administration is keen to enumerate the barriers that require assessment and improvements. The service quality level will be impacted by these barriers. The goal is to attain the 'extremely good service quality', level 5, which is the highest possible level. The criteria performance barrier index (CPI) can be used to recognize such barriers. Equation (9) was used to compute it. A sample calculation for the CPI of service criterion C28 (refer to Table 13) is presented below.

$$\mathrm{CPI}_{k=28}^{i=2,j=4} = \mathrm{CPI}_{28}^{2,4} = \left(1 - \mathrm{W}_{k=28}^{i=2,j=4}\right) \times \mathrm{R}_{k=28}^{i=1,j=1}$$
$$\equiv [(1,1,1) - (0.48, 0.68, 0.88)] \times (0.27, 0.47, 0.67)$$
$$\equiv (0.52,\ 0.32,\ 0.12) \times (0.27, 0.47, 0.67) \equiv (0.140,\ 0.150,\ 0.080)$$

$$\mathrm{CPI}_{28}^{2,4} = (0.140,\ 0.150,\ 0.080) \equiv (\Theta, \varnothing, \Psi)$$

Thus, the CPI is computed and depicted below in Table 19 for all seventy-eight service criteria. However, the CPI needs to be ranked, and the ranking score based on the centroid approach is determined by using Equation (10).

Using Equation (10), the ranking scores of the CPI for all service quality criteria are calculated. The calculation for C28 is shown below as an example.

Ranking score for service criterion C28 (k = 28) is equal to

$$\left(\frac{0.1404 + 6 \times 0.1504 + 0.0804}{6}\right) = 0.187$$

In the same manner, all hospital service criteria ranking scores are calculated and shown in Table 19, and then they are ranked accordingly.

Table 19. Hospital service criteria ranking scores and rankings based on CPI.

k *↓	$\mathrm{CPI}_k^{i,j}$			Ranking Score	Rank	k *↓	$\mathrm{CPI}_k^{i,j}$			Ranking Score	Rank	k *↓	$\mathrm{CPI}_k^{i,j}$			Ranking Score	Rank
	$\boldsymbol{\theta}$	Ø	Ψ				$\boldsymbol{\theta}$	Ø	Ψ				$\boldsymbol{\theta}$	Ø	Ψ		
C01 [@]	0.255	0.221	0.107	0.281	31	**C27**	0.278	0.218	0.078	0.278	36	**C53**	0.213	0.205	0.116	0.259	45
C02	0.046	0.122	0.119	0.150	76	**C28**	0.140	0.150	0.080	0.187	68	**C54**	0.287	0.261	0.156	0.335	13
C03	0.106	0.152	0.153	0.195	63	**C29**	0.107	0.123	0.076	0.154	75	**C55**	0.279	0.246	0.133	0.315	18
C04	0.020	0.067	0.095	0.086	78	**C30**	0.092	0.098	0.024	0.118	77	**C56**	0.279	0.246	0.133	0.315	17
C05	0.305	0.278	0.172	0.358	10	**C31**	0.216	0.148	0.000	0.184	70	**C57**	0.245	0.199	0.073	0.252	47
C06	0.271	0.220	0.089	0.280	34	**C32**	0.220	0.150	0.000	0.187	69	**C58**	0.252	0.208	0.085	0.264	42
C07	0.293	0.299	0.224	0.385	7	**C33**	0.223	0.196	0.090	0.248	49	**C59**	0.270	0.230	0.110	0.294	26
C08	0.103	0.134	0.097	0.168	73	**C34**	0.257	0.232	0.128	0.296	25	**C60**	0.182	0.209	0.156	0.265	41
C09	0.211	0.233	0.175	0.298	24	**C35**	0.252	0.244	0.155	0.311	20	**C61**	0.239	0.244	0.169	0.312	19
C10	0.205	0.213	0.140	0.270	39	**C36**	0.182	0.176	0.090	0.221	58	**C62**	0.260	0.224	0.108	0.285	30
C11	0.155	0.215	0.227	0.278	35	**C37**	0.263	0.221	0.098	0.281	33	**C63**	0.294	0.276	0.178	0.355	11
C12	0.253	0.271	0.208	0.348	12	**C38**	0.276	0.234	0.112	0.298	23	**C64**	0.411	0.410	0.329	0.533	1
C13	0.122	0.182	0.162	0.230	56	**C39**	0.224	0.211	0.119	0.269	40	**C65**	0.360	0.350	0.260	0.454	4
C14	0.156	0.206	0.176	0.262	43	**C40**	0.240	0.196	0.072	0.248	50	**C66**	0.264	0.260	0.177	0.334	14
C15	0.161	0.224	0.207	0.285	29	**C41**	0.157	0.156	0.076	0.195	64	**C67**	0.129	0.187	0.165	0.236	54
C16	0.197	0.190	0.103	0.240	53	**C42**	0.212	0.185	0.077	0.233	55	**C68**	0.104	0.153	0.122	0.191	67
C17	0.208	0.192	0.096	0.243	51	**C43**	0.306	0.284	0.182	0.365	8	**C69**	0.192	0.182	0.092	0.230	57
C18	0.177	0.221	0.185	0.281	32	**C44**	0.235	0.228	0.140	0.290	27	**C70**	0.208	0.192	0.096	0.243	52
C19	0.156	0.157	0.083	0.197	61	**C45**	0.281	0.258	0.154	0.330	16	**C71**	0.146	0.154	0.082	0.191	66
C20	0.299	0.359	0.340	0.466	3	**C46**	0.094	0.139	0.105	0.172	71	**C72**	0.196	0.215	0.154	0.273	38
C21	0.245	0.199	0.073	0.252	46	**C47**	0.265	0.227	0.109	0.290	28	**C73**	0.130	0.132	0.054	0.162	74
C22	0.301	0.260	0.139	0.333	15	**C48**	0.247	0.235	0.144	0.300	22	**C74**	0.224	0.216	0.128	0.275	37
C23	0.266	0.205	0.065	0.260	44	**C49**	0.333	0.322	0.231	0.416	5	**C75**	0.218	0.172	0.047	0.216	59
C24	0.382	0.375	0.288	0.487	2	**C50**	0.228	0.154	0.000	0.192	65	**C76**	0.151	0.169	0.107	0.212	60
C25	0.321	0.284	0.166	0.365	9	**C51**	0.252	0.197	0.063	0.250	48	**C77**	0.182	0.157	0.053	0.196	62
C26	0.336	0.304	0.192	0.392	6	**C52**	0.258	0.243	0.147	0.310	21	**C78**	0.167	0.139	0.031	0.172	72

Notes: *, [@], please see Table 2.

Thus, in order to determine the barriers to service quality, a threshold value must be determined. As demonstrated below, the threshold value is determined using Equation (11):

$$\text{The threshold value for the hospital} = \left(\frac{(0.269 + 4 * 0.086 + 0.533)}{6}\right) = 0.191$$

For the organization, 0.191 is the threshold value. Consequently, 12 service criteria whose performance was below the threshold value are listed in Table 20 below, which was created by comparing this threshold value as a benchmark with the hospital service quality criteria fuzzy ranking scores from Table 19. Thus, these 12 service standards might be thought of as barriers to high-quality services. Management will make sure that the hospital's weaker areas are improved, raising the service quality level from 4 to 5.

Table 20. Service criteria considered as barriers to the hospital's overall service quality.

Service Dimension (i)	Factor (j)	Criterion (k)	Ranking Score
D01: PMS	F01: Accessibility and arrival factors	C04: Public transport accessibility to reach hospital premises	0.086
		C02: Sufficient parking is available in the hospital premises	0.150
		C08: How is the ambulance service	0.168
D02: PPR	F04: Medical consultation/treatment factors	C30: Individual attention to patients	0.118
		C29: Physicians are available whenever customers need medical services	0.154
		C31: Physicians review patient medical history and take care of patient allergies	0.184
		C32: Physicians have knowledge and adequate information on treatment	0.187
		C28: The time it took to meet doctor is not too long	0.187
	F05: Post-consultation/ treatment factors	C46: Hospital staff ask for feedback from the customers after treatment	0.172
D03: PRM	F07: Appearance and behavior (staff and facilities)	C68: Hospital staff properly handle any problems that arise	0.191
	F08: Customer satisfaction and loyalty	C73: The hospital gets things right the first time	0.162
		C78: I will recommend this hospital to others, and will visit it again if required	0.172

After transferring the data to the evaluation interface, the single index and the barrier criteria are estimated using the several equations needed to evaluate the hospital service quality, which are explained in Section 3. Figure 6 shows the developed GUI's management interface, which helps to identify the hospital service quality and barrier criteria with a single click.

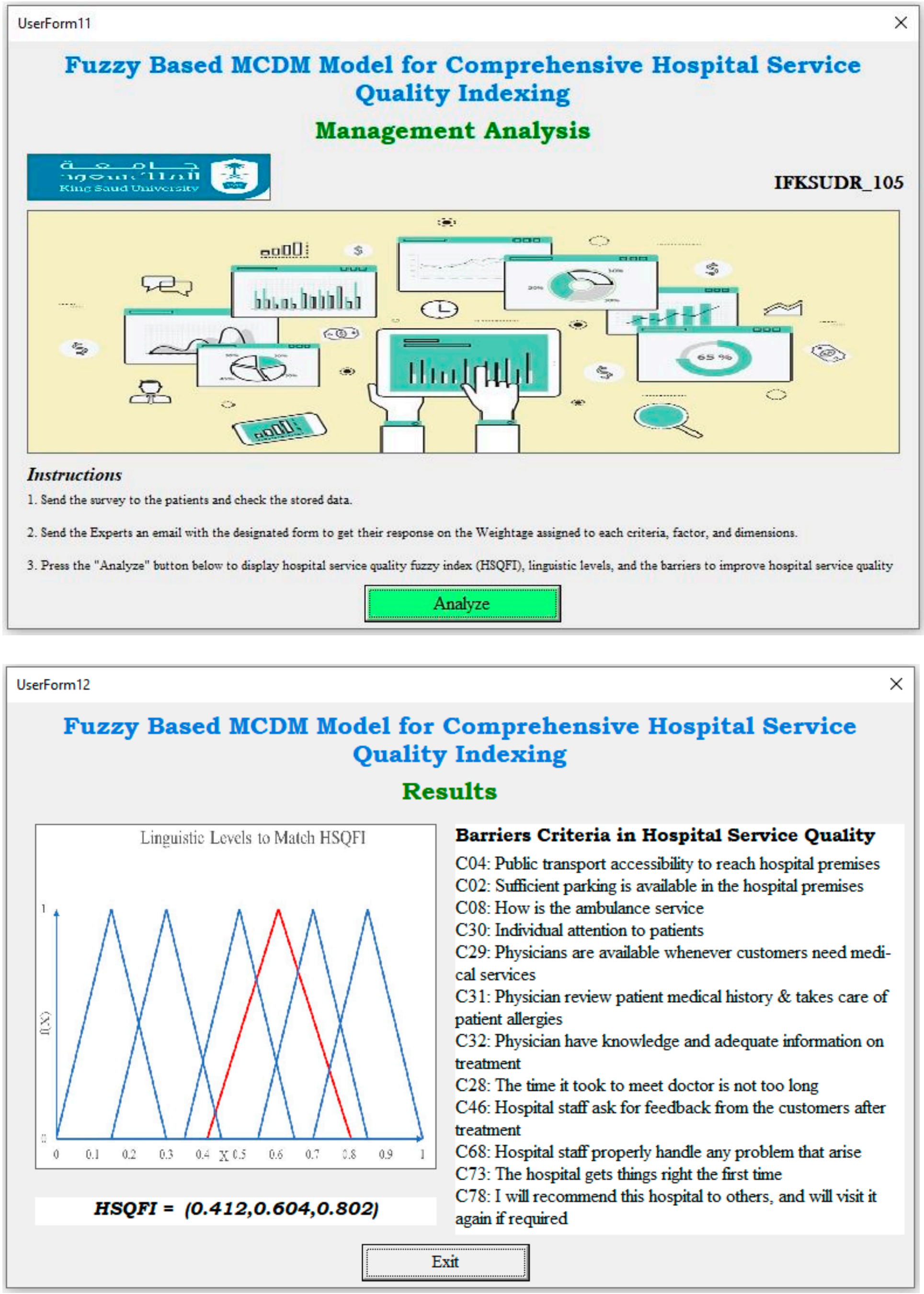


Figure 6. Screenshots of the management analysis interface.

Thus, it is evident that the above study addresses a critical need in the healthcare industry, which is the evaluation of service quality. In today's competitive healthcare market, understanding and improving service quality is paramount for any hospital. The proposed model offers a holistic way to assess various dimensions and criteria, providing a single, easy-to-understand performance measure. The case study discusses how several service quality criteria and factors of a hospital are combined, as well as how the hospital service quality index is estimated using a variety of performance metrics. Consequently, it makes it possible for the hospital organization's management to analyze the service index, which serves as a management and governance tool. This is particularly important to enhance patient satisfaction, trust, and financial viability for a given healthcare organization.

This research work identified eight factors and 78 criteria, along with three service dimensions for measuring hospital service quality (refer to Table 2). Using the fuzzy logic approach, the HSQFI is calculated, which is equal to $(0.412, 0.604, 0.802)$. Then, by calculating the HSQL and using Euclidean distance, it was revealed that the case organization was at a good service level (refer to Table 18). Nevertheless, it was below an extremely good service level. However, a few barriers impact the overall level of service quality. To identify these barriers, the CPI was calculated (refer to Table 19). Table 16 indicates that the following hospital service parameters, which are the lowest ranked, need to be improved: C04, C02, C08, C30, and C29. The service quality barrier, C68, has a score of 0.191 (Table 20), or equal to the threshold value. In this case, the management needs to focus on hospital staff training so that they can properly handle any problem that arises related to staff. C28 and C32 received ranking scores of 0.187, which is slightly below the 0.191 threshold value, indicating that the management needs to focus on improving physician knowledge, and provide adequate, up-to-date training on treatment, and should work to reduce patient waiting times for physicians. Thus, by identifying specific barriers to improvement based on the lowest-ranked hospital service criteria, the hospital management can focus its resources more effectively. Moreover, this approach can guide decision-makers in making informed choices to improve overall service quality.

5. Conclusions

Decision-makers need to be aware of their organizations' service quality status, especially in healthcare, since it directly deals with human life. These days, service quality in the healthcare sector has become a crucial subject. It is being used as a strategy to thrive in a demanding business environment. Hence, it is vital to focus on healthcare service quality for developing nations since their living conditions are challenging day by day. However, there is still a lack of a comprehensive method to assess and validate hospital service quality barriers. On the other hand, the dynamic and vague nature of customers' feedback makes it more difficult to measure and analyze service quality. So, in this research work, an intuitive GUI-based fuzzy multi-criteria decision model is developed for hospital service quality evaluation to answer the research questions mentioned in Section 1. The following main conclusions are inferred from the study:

- The selection of appropriate service dimensions, factors, and criteria is vital in obtaining better results when assessing the hospital service quality.
- Periodic assessments are necessary to ensure management knows how far their organization has to go to achieve their targeted service quality.
- A graphical user interface (GUI) is developed for collecting data, and then it shows the results in the form of barriers and recommendations.
- Based on the case study it can be said that the proposed methodology works well in combining various dimensions, factors, and criteria, and results in a single easy-to-understand index. And it is benchmarked to identify the barriers (i.e., service criteria) for improving overall service quality.
- The dynamic nature of healthcare and changing patient expectations necessitate periodic service quality assessments.

In addition to improving hospital service quality, this study also has the potential to help in making healthcare policies and strategies at hospital, regional, or national level. As the healthcare landscape continually evolves, this study provides valuable insights for policymakers and healthcare administrators to make informed decisions, allocate resources efficiently, and prioritize patient-centered care. By integrating the HSQFI into healthcare policy and regulatory frameworks, one can work towards a future where healthcare services are consistently enhanced, patient satisfaction is prioritized, and the quality of care provided is continually monitored and improved. With the help of HSQFI, the policy makers can benchmark the hospital service quality and improve the criteria that are barriers to reaching the desired level.

The research work has limitations, such as potential subjectivity and biases. For example, the determination of weights and ratings in the model relies on expert opinions and customer responses, which can introduce variability in the results. Similarly, the outcomes may vary for other countries, metropolises, establishment sizes, and health organizations with different domains, dimensions, factors, and criteria. To mitigate this, future research could explore methods to reduce subjectivity and increase the objectivity of criteria selection and ratings determination. Such future research could be conducted for a number of other healthcare organizations. Subsequently, future research could use other contemporary techniques and tools, such as artificial intelligence, to improve the current index's efficacy.

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Data Availability Statement: All the relevant data are available in the article, and further can be obtained from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Some more screen shots of the developed GUI are shown below in Figure A1.

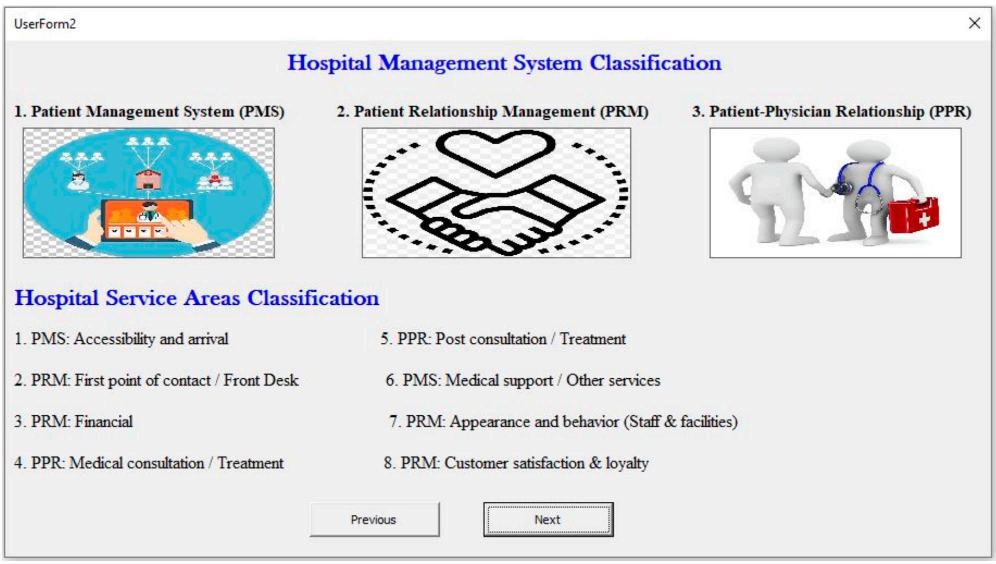

Figure A1. *Cont.*

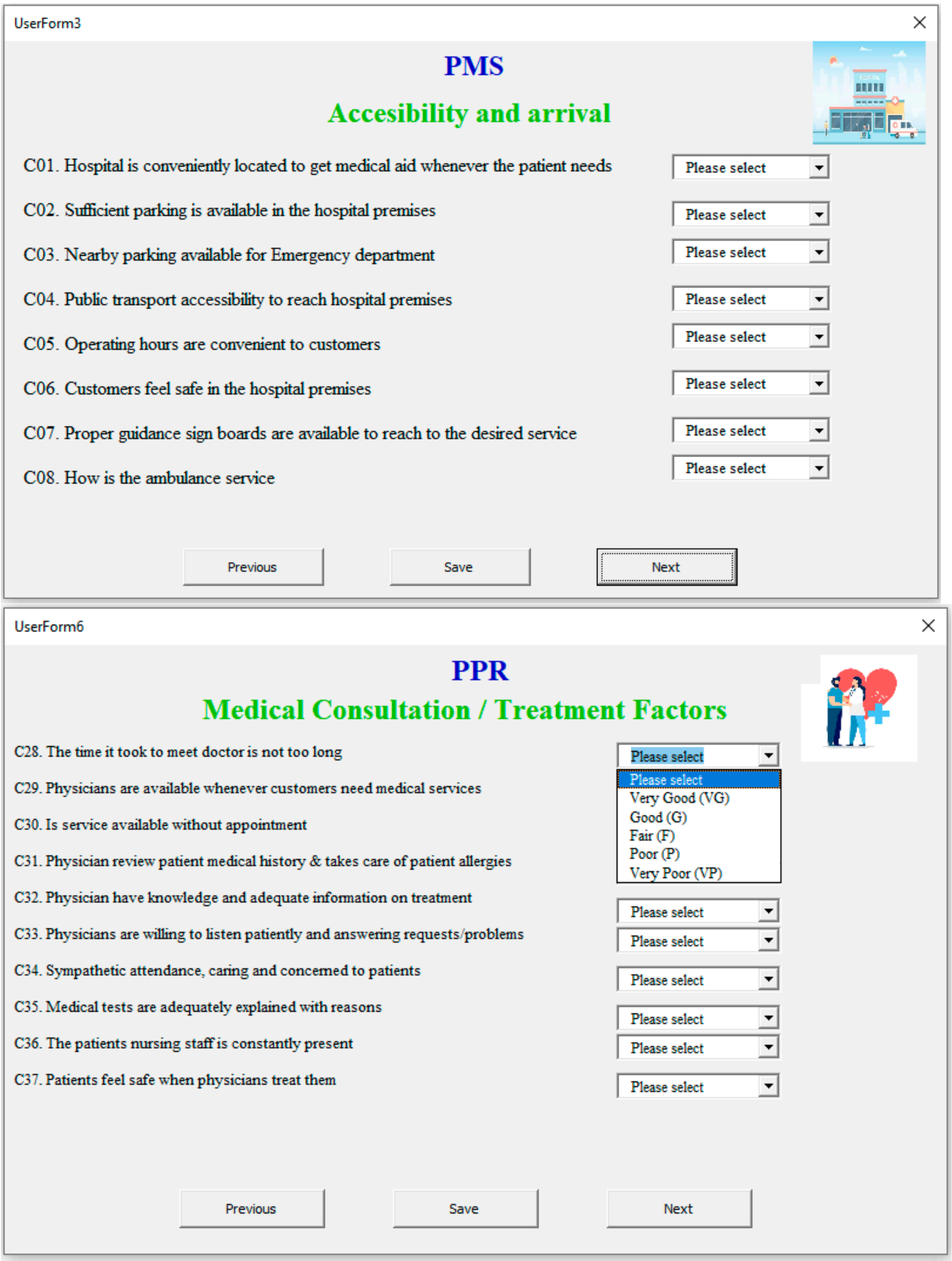

Figure A1. Some more screenshots of the data input interface.

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