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METHODOLOGIES AND APPLICATION

# Hospital service quality evaluation: an integrated model based on Pythagorean fuzzy AHP and fuzzy TOPSIS

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## Abstract

Providing better hospital service quality is one of the major concerns of healthcare industry in the world. Since health services in Turkey are provided in a very competitive environment, for making a better choice, the services delivered by the public and private hospitals should be evaluated according to the viewpoint of stakeholders in terms of satisfaction. In this study, a model proposal is presented based on the concept of Pythagorean fuzzy analytic hierarchy process and Pythagorean fuzzy technique for order preference by similarity to ideal solution method to provide an accurate decision-making process for evaluating the hospital service quality. We study under fuzzy environment to reduce uncertainty and vagueness, and use linguistic variables parameterized by Pythagorean fuzzy numbers. The proposed approach is separated from others with the integration of the methods in a way providing a systematic fuzzy decision-making process. A case study including 32 service quality criteria and two public and one private hospitals in Turkey assessed by 32 evaluators by medical staff, hospital executives, auxiliaries, and patients is performed to demonstrate the applicability and validity of the proposed approach. On conclusion, integrated model produces reliable and suggestive outcomes better representing the vagueness of decision-making process.


**Keywords** Service quality · Public and private hospitals · Pythagorean fuzzy sets · PFAHP · PFTOPSIS

## 1 Introduction

Providing better hospital service quality is one of the major concerns of healthcare industry over the world (Chang 2014; Akdag et al. 2014; Taşkin et al. 2015). Delivery of healthcare services in Turkey is performed in a very competitive environment. For that reason, to make a better choice, the services provided by the public and private hospitals should be monitored and evaluated according to the viewpoint of stakeholders such as patients, medical staff, and hospital executives in terms of more satisfaction.

In recent years, great effort has been spent to improve the health system in Turkey. Key elements of the reforms under the health transformation program implemented include the development of private healthcare institutions and the improvement in the quality of services provided by both public and private hospitals (Demirer and Bülbül 2014). The increase in the number of private healthcare facilities in the health sector, despite the huge role of public health sector, is one of the indicators of the efforts to improve the healthcare system. In 2015, the number of hospitals in Turkey reached 1533. In 2014, the number of hospitals in the Ministry of Health was 866, while in 2015 it reached to 865. The number of university hospitals, which was 69 in 2014, reached 70 in 2015. Also, the number of private hospitals, which was 562 in 2014, increased to 556 in 2015 (Ministry of Health 2016). In 2015, number of medical staff per 100.000 employees increased compared to the previous year. In 2014, the number of specialist physicians per 100,000 people was 97, but in 2015 it reached 99. The number of nurses and the number of midwives per 100,000 persons increased from 251 in 2014 to 261 in 2015, which is an increase compared

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to 2014 in all titles. The number of nurses and midwives per 100,000 persons (251 in 2014 to 261 in 2015) increased in all the titles compared to 2014 (Ministry of Health 2016). Regarding the improvement in public health sector, public and university hospital admissions have increased since 2014. When the admission rates are examined, admissions to public and university hospitals have increased in 2016 compared to 2014 (while public hospital admissions are changed from approximately 292 million to 340 million, university hospital admissions are 32 million to 36 million). Contrary to this figure, regarding positive service quality provided by public hospitals in recent periods, in 2014 admissions to private healthcare institutions decreased with a small change (72 to 71 million) (Ministry of Health 2017; Ministry of Health 2015). Despite the continuous increase in the number of patients admitted and the number of hospitals in Turkey, there is lack of enough attempts about service quality evaluation in terms of hospital types. On the other hand, millions of people continue to receive health services from public hospitals, although private hospitals are increasingly located in the Turkish healthcare system. For this reason, a reliable and accurate approach is needed in order to measure and improve both public and private hospital service quality.

Therefore, in this study, a novel approach is proposed based on the concept of Pythagorean fuzzy sets, AHP, and TOPSIS method to provide an accurate decision-making process for evaluating the hospital service quality. Multi-criteria decision-making (MCDM) is an important field of management science, which clearly reflects multiple criteria in decision-making environments. It includes several kinds of methodologies for decision makers and practitioners. MCDM-based methods heavily include human participation and judgments (Kubler et al. 2016). It deals with evaluating, prioritizing, or selecting alternatives under conflicting criteria with respect to decision maker(s) preferences (Gul et al. 2016). The main mechanisms of a MCDM method are itemized as alternatives, criteria against evaluated alternatives, scores of alternatives on the criteria, and criteria weights reflecting relative importance of each criterion as compared with others (Gul et al. 2016). One of the most important MCDM methods widely used is AHP. In the healthcare service quality evaluation literature, researchers apply AHP mostly to determine scores/weights of service quality criteria in a hierarchical manner (Min et al. 1997; Wu et al. 2008; Afkham et al. 2012; Akdag et al. 2014; Aktas et al. 2015; Lupo 2016). To this end, in the literature, the fuzzy set theory is used to take vagueness and uncertainty of subjective evaluations into consider. AHP proposed by Thomas L. Saaty is based on the hierarchical MCDM problem consisting of a goal, criteria, and alternatives. In each hierarchical level, pairwise comparisons are made with judgments using numerical values taken from the Saaty's scale of 1–9 (Saaty 1990). The process of AHP provides to weight criteria and defines a ranking of the alternatives. The decision-making process begins with a comparison of the alternatives with respect to the criteria. The evaluation continues up to the criteria of the first level and then these are compared to the goal. AHP has the advantages of hierarchical structure definition, demonstration of the problem in a structural manner and integration of all the judgments with structured links. After the hierarchy is structured, linguistic terms are employed by experts to make pairwise comparisons. These linguistic terms are converted to numerical values by using fuzzy sets which are able to handle uncertainty and vagueness of evaluation processes. Therefore, it is possible to say that AHP is quite useful for modeling problems in the absence of certain measures.

In this study, Pythagorean fuzzy AHP is used to make the developed hospital service quality evaluation model more effectively. *Pythagorean fuzzy sets* are an extension of intuitionistic fuzzy sets. They provide more autonomy to decision makers in articulating their ideas about the vagueness and uncertainty of the considered MCDM problem. Pythagorean fuzzy sets achieve this purpose because decision makers do not have to assign membership and non-membership degrees whose sum is at most 1 (Ilbahar et al. 2018). However, the sum of squares of these degrees must be at most 1. The weights of 32 hospital service quality evaluation criteria are obtained through Pythagorean fuzzy analytic hierarchy process (PFAHP). In the health service quality evaluation literature, PFTOPSIS is used by researchers in order to determine priorities of the healthcare institutions like hospitals (Akdag et al. 2014). The obtained values for above-mentioned 32 criteria will be used as inputs for PFTOPSIS, and it will provide a ranking order among hospital types as an output.

The rest of this paper is structured as follows: A literature review on the general view of healthcare service quality and MCDM-based hospital service quality evaluation is given in Sect. 2. Preliminaries on Pythagorean fuzzy sets, linguistic variables parameterized by Pythagorean fuzzy numbers, steps of PFAHP, and PFTOPSIS are examined in Sect. 3. Application of the PFAHP and PFTOPSIS-integrated model proposal and conclusions are presented in Sects. 4 and 5, respectively.

## 2 Review of literature

In the context of this study, a broad literature review has been done to show current attempts about healthcare service quality evaluation. The related literature is divided into two parts as follows: (1) studies applied a

SERVQUAL-based healthcare service quality evaluation model, and (2) studies applied a single or hybrid MCDM-based healthcare service quality evaluation model. SERVQUAL is a common used method to measure service quality in the literature (Parasuraman et al. 1988). This method is a survey analysis based on evaluation of perceived and expected service quality by customers. With the results of the evaluation, the gap between service expectations (e.g., required quality as important–unimportant) and the performance level of the service (e.g., good–poor perceived quality) determines the quality of the service. In other words, evaluation of service quality in SERVQUAL analysis is based on calculating the difference between the scores which the customers respond to the pairs of expressions "*expectation–perception*" (Demir et al. 2018). SERVQUAL is applied to many service industries such as healthcare (Altuntas et al. 2012), transportation (Kayapinar and Erginel 2017), education (Lupo 2013), banking (Ali and Raza 2017), and safety (Demir et al. 2018). Regarding healthcare service quality, SERVQUAL is mentioned by many researchers. Altuntas et al. (2012) measured hospital service quality by using analytic hierarchy process (AHP) and analytic network process (ANP) to acquire the relationship and the level of the importance among SERVQUAL dimension. They evaluated the perceived service quality with respect to different hospital classes in Turkey and compared AHP- and ANP-based weighted SERVQUAL scales with the unweighted SERVQUAL scale for public hospital service quality in terms of different hospital classes (A–B and C). Afkham et al. (2012) proposed a fuzzy-based method. SERVQUAL model was used to evaluate the respondents' judgments of service quality. Fuzzy AHP was applied to obtain weights of SERVQUAL dimensions and TOPSIS for ranking the hospitals. Chakravarty (2011) evaluated service quality of hospital outpatient departments using SERVQUAL. Service quality gaps were identified across all the five dimensions of the survey instrument. Significant gaps across the dimensions of "tangibles" and "responsiveness" were found. The quality gaps were further validated by a total unweighted SERVQUAL score of (–) 1.63. That study is the first attempt for service quality evaluation of hospital outpatient departments. Similarly, Teng et al. (2007) focused on surgical hospitalization using SERVQUAL. Lee et al. (2000) proposed three different methods for measuring healthcare service quality. These methods were not addressed in the previous studies. The performance of the constant-sum rating method, the single-item global rating method, and multi-item rating method in measuring the healthcare service quality was compared. That study also included two additional dimensions to SERVQUAL as core medical service and professionalism/skill assessed by physicians. Demirer and Bülbül (2014) comparatively explored the suitability of SERVQUAL and the relationship between perceived service quality, patient satisfaction, and patient preference for the public and private hospitals in Turkey. Lupo (2016) analyzed public healthcare sector of the Sicily region (Italy) via a SERVQUAL-based framework. Also, FAHP was employed to obtain reliable estimations of service quality expectations. Handayani et al. (2015) used a different dimension to classical SERVQUAL called professionalism. Using entropy method, strategic hospital service quality criteria were weighted. Shieh et al. (2010) combined SERVQUAL and decision-making trial and evaluation laboratory (DEMATEL) methods in identifying key success factors of hospital service quality. Firstly, a survey based on SERVQUAL model was conducted to identify seven major criteria from patients' or their families' viewpoints at a hospital in Taiwan. Then, a second survey was developed for applying DEMATEL method to evaluate the importance of criteria and construct the causal relations among the criteria.

Unlike SERVQUAL-based studied, limited number of studies stand in the literature in conjunction with MCDM, fuzzy sets and healthcare service quality evaluation. Aktas et al. (2015) developed a service quality index in order to present a basis for classification of hospitals by using MCDM tools with respect to the criteria in the literature. In the scope of this study, service quality criteria were determined and weights of them were obtained by AHP from the viewpoint of service providers and patients. Then, a formulation was developed to obtain service quality index (SQI) for hospitals. Lin et al. (2013) integrated hierarchical balanced scorecard with fuzzy linguistic for evaluating operating room performance in hospitals. Initially, a model was developed for measuring the acceptable performance of operating room based on the interaction financial, customers, internal business process, and learning and growth perspective. Then, balanced scorecard integrated with fuzzy linguistic was proposed for measuring the service. Taşkin et al. (2015) and Chang (2014) benefited from VIKOR method in hospital service quality evaluation. Both studies applied the fuzzy MCDM approach to determine the importance weights of evaluation criteria and the VIKOR method to prioritize feasible alternatives. For each of them, an empirical case involving 33 evaluation criteria and two public and three private medical centers in Turkey and Taiwan assessed by 18 evaluators from various fields of medical industry was presented. Akdag et al. (2014) applied TOPSIS method separated from Taşkin et al. (2015) and Chang (2014) to evaluate the service quality of some Turkish hospitals. In this study, importance weights of criteria were found with AHP. Then, the TOPSIS and Yager's min–max approach were applied to rank hospitals. As a follow-up study, an aggregation of performance criteria with ordered weighted averaging (OWA) and compensatory AND operators are looked at instead of the TOPSIS method and min–max approach, and the obtained results were compared.

After examining the relevant literature, it is believed and concluded that the current study contributes to the knowledge of hospital service quality evaluation by some innovations: (1) First time in hospital environments, a PFAHP-based hybrid MCDM approach was used to obtain importance weights to the service quality criteria by using interval-valued Pythagorean fuzzy linguistic scale and pairwise comparison manner. (2) In the current literature, there is still no attempt to evaluate service quality performance of public and private hospitals from the viewpoint of various expert groups. Therefore, this paper aims to fill the gap in this area using the proposed approach (PFAHP–PFTOPSIS). This approach offers the opportunity to make assessments considering experts' subjective judgments that are closer to the human mind than other options in the hospital performance evaluation. (3) On conclusion of this study, it is expected to represent a basis for decisions and policies that must be taken by any hospital authorities as part of their health delivery processes.

## 3 Proposed methodology

### 3.1 Pythagorean fuzzy sets

Intuitionistic fuzzy sets first proposed by Atanassov (1986) and have been used by many researchers in different fields to address uncertainty. These sets can be expressed in terms of membership functions, non-membership function and hesitancy degree. However, in some cases, it fails to fulfill the condition when there are times the degree of membership and non-membership is bigger than 1. Obviously, intuitionistic fuzzy sets are unable to capture the situation. As a result, Yager (2014) developed Pythagorean fuzzy sets. These sets are the generalization to the intuitionistic fuzzy sets in some condition intuitionistic fuzzy sets cannot address the uncertainty. This achievement makes Pythagorean fuzzy sets more powerful and flexible to solve problems involving uncertainty (Mohd and Abdullah 2017; Ilbahar et al. 2018; Gul 2018; Gul and Ak 2018; Oz et al. 2018; Mete 2018; Gul et al. 2018).

In Pythagorean fuzzy sets, unlike the intuitionistic fuzzy sets, the sum of membership and non-membership degrees can exceed 1 but the sum of squares cannot (Ilbahar et al. 2018; Zeng et al. 2016; Zhang and Xu 2014). This situation is shown below in Definition (1).

**Definition 1** Let a set X be a universe of discourse. A Pythagorean fuzzy set $P$ is an object having the form (Zhang and Xu 2014):

$$P = \{ < x,\ P(\mu_P(x), v_P(x)) > | x \in X\} \quad (1)$$

where $\mu_P(x) : X \mapsto [0, 1]$ defines the degree of membership and $v_P(x) : X \mapsto [0, 1]$ defines the degree of non-membership of the element $x \in X$ to $P$, respectively, and, for every $x \in X$, it holds:

$$0 \le \mu_P(x)^2 + v_P(x)^2 \le 1 \quad (2)$$

For any PFS P and $x \in X$, $\pi_P(x) = \sqrt{1 - \mu_P^2(x) - v_P^2(x)}$ is called the degree of indeterminacy of $x$ to $P$.

**Definition 2** Let $\beta_1 = P(\mu_{\beta_1}, v_{\beta_1})$ and $\beta_2 = P(\mu_{\beta_2}, v_{\beta_2})$ be two Pythagorean fuzzy numbers, and $\lambda > 0$, then the operations on these two Pythagorean fuzzy numbers are defined as follows (Zeng et al. 2016; Zhang and Xu 2014):

$$\beta_1 \oplus \beta_2 = P\left(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - \mu_{\beta_1}^2 \mu_{\beta_2}^2},\ v_{\beta_1} v_{\beta_2}\right) \quad (3)$$

$$\beta_1 \otimes \beta_2 = P\left(\mu_{\beta_1} \mu_{\beta_2},\ \sqrt{v_{\beta_1}^2 + v_{\beta_2}^2 - v_{\beta_1}^2 v_{\beta_2}^2}\right) \quad (4)$$

$$\lambda\beta_1 = P\left(\sqrt{1 - \left(1 - \mu_{\beta_1}^2\right)^{\lambda}}, (v_{\beta_1})^{\lambda}\right), \lambda > 0 \quad (5)$$

$$\beta_1^{\lambda} = P\left((\mu_{\beta_1})^{\lambda}, \sqrt{1 - \left(1 - v_{\beta_1}^2\right)^{\lambda}}\right), \lambda > 0 \quad (6)$$

**Definition 3** Let $\beta_1 = P\left(\mu_{\beta_1}, v_{\beta_1}\right)$ and $\beta_2 = P\left(\mu_{\beta_2}, v_{\beta_2}\right)$ be two Pythagorean fuzzy numbers, a nature quasi-ordering on the Pythagorean fuzzy numbers is defined as follows (Zhang and Xu 2014):

$\beta_1 \ge \beta_2$ if and only if $\mu_{\beta_1} \ge \mu_{\beta_2}$ and $v_{\beta_1} \le v_{\beta_2}$

A score function is proposed to compare two Pythagorean fuzzy numbers by (Zhang and Xu 2014) as follows:

$$s(\beta_1) = (\mu_{\beta_1})^2 - (v_{\beta_1})^2 \quad (7)$$

**Definition 4** Based on the score functions proposed above, the following laws are defined to compare two Pythagorean fuzzy numbers (Zhang and Xu 2014):

(i) If $s(\beta_1) < s(\beta_2)$, then $\beta_1 \prec \beta_2$
(ii) If $s(\beta_1) > s(\beta_2)$, then $\beta_1 \succ \beta_2$
(iii) If $s(\beta_1) = s(\beta_2)$, then $\beta_1 \sim \beta_2$

### 3.2 PFAHP and related linguistic terms

In this sub-section, we will give the steps of PFAHP method.

*Step 1* The compromised pairwise comparison matrix $A = (a_{ik})_{m \times m}$ is structured based on linguistic evaluation of experts using the scale proposed by (Ilbahar et al. 2018) in Table 1.

**Table 1** Weighting scale for PAHP (Ilbahar et al. 2018)

| Linguistic term | Pythagorean fuzzy numbers | | | |
|---|---|---|---|---|
| | $\mu_L$ | $\mu_U$ | $v_L$ | $v_U$ |
| Certainly low important (CLI) | 0.00 | 0.00 | 0.90 | 1.00 |
| Very low important (VLI) | 0.10 | 0.20 | 0.80 | 0.90 |
| Low important (LI) | 0.20 | 0.35 | 0.65 | 0.80 |
| Below average important (BAI) | 0.35 | 0.45 | 0.55 | 0.65 |
| Average important (AI) | 0.45 | 0.55 | 0.45 | 0.55 |
| Above average important (AAI) | 0.55 | 0.65 | 0.35 | 0.45 |
| High important (HI) | 0.65 | 0.80 | 0.20 | 0.35 |
| Very high important (VHI) | 0.80 | 0.90 | 0.10 | 0.20 |
| Certainly high important (CHI) | 0.90 | 1.00 | 0.00 | 0.00 |
| Exactly equal (EE) | 0.1965 | 0.1965 | 0.1965 | 0.1965 |

*Step 2* The difference matrices $D = (d_{ik})_{m\times m}$ between lower and upper values of the membership and non-membership functions are calculated using Eqs. (8) and (9):

$$d_{ik_L} = \mu^2_{ik_L} - v^2_{ik_U} \tag{8}$$

$$d_{ik_U} = \mu^2_{ik_U} - v^2_{ik_L} \tag{9}$$

*Step 3* Interval multiplicative matrix $S = (s_{ik})_{m\times m}$ is computed using Eqs. (10) and (11):

$$s_{ik_L} = \sqrt{1000^{d_L}} \tag{10}$$

$$s_{ik_U} = \sqrt{1000^{d_U}} \tag{11}$$

*Step 4* The determinacy value $\tau = (\tau_{ik})_{m\times m}$ is calculated using Eq. (12):

$$\tau_{ik} = 1 - \left(\mu^2_{ik_U} - \mu^2_{ik_L}\right) - \left(v^2_{ik_U} - v^2_{ik_L}\right) \tag{12}$$

*Step 5* The determinacy degrees are multiplied with $S = (s_{ik})_{m\times m}$ matrix for obtaining the matrix of weights, $T = (t_{ik})_{m\times m}$ before normalization using Eq. (13).

$$t_{ik} = \left(\frac{s_{ik_L} + s_{ik_U}}{2}\right)\tau_{ik} \tag{13}$$

*Step 6* The normalized priority weights $w_i$ is computed by using Eq. (14).

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}} \tag{14}$$

## 4 PFTOPSIS

The TOPSIS was developed by Hwang and Yoon (1981) to find out the best alternative based on the compromise solution concept. The compromise solution concept can be regarded as selecting the solution with the shortest distance from the ideal solution and the farthest distance from the negative ideal solution. Since the ratings while evaluating alternatives against criteria usually refer to the subjective uncertainty, TOPSIS is extended to consider the situation of fuzzy numbers (Chen 2000; Tzeng and Huang 2011; Celik et al. 2012). The steps of FTOPSIS can be reached in (Tzeng and Huang 2011; Kutlu and Ekmekçioğlu 2012; Gul and Guneri 2018; Carpitella et al. 2018).

Pythagorean fuzzy sets are an extension of usual and intuitionistic fuzzy sets. It provides more freedom to experts in expressing their opinions about the vagueness and uncertainty of the considered problem. In Pythagorean fuzzy sets experts assign membership and non-membership degrees. On the other hand, TOPSIS method is applied to a variety of problems in the literature. It has many advantages as follows: It allows the experts to assign judgments by means of linguistic terms, which are better interpreted by humans, fuzzy in nature, and then transferred into Pythagorean fuzzy numbers. It has more capability in handling uncertainties, simultaneous consideration of the positive and the negative ideal points, simple computation, and logical concept.

Based on definitions given above, in the following, PFTOPSIS algorithm is presented with its routine steps (Oz et al. 2018).

*Step 1* Initially, decision matrix under Pythagorean fuzzy sets $R = (C_j(x_i))_{m\times n}$ is constructed. Here, $C_j(j = 1, 2, \ldots, n)$ and $x_i(i = 1, 2, \ldots, m)$ refer to values of criteria and alternatives. The matrix form is as follows:

$$R = (C_j(x_i))_{mxn} = \begin{pmatrix} P(u_{11}, v_{11}) & P(u_{12}, v_{12}) & \ldots & P(u_{1n}, v_{1n}) \\ P(u_{21}, v_{21}) & P(u_{22}, v_{22}) & \ldots & P(u_{2n}, v_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ P(u_{m1}, v_{m1}) & P(u_{m2}, v_{m2}) & \ldots & P(u_{mn}, v_{mn}) \end{pmatrix}$$

*Step 2* Secondly, Pythagorean fuzzy positive ideal solution (PIS) and negative ideal solutions (NIS) are determined using Eqs. (15, 16) as follows:

$$x^+ = \left\{C_j, \max_i\langle s(C_j(x_i))\rangle | j = 1, 2, \ldots, n\right\} = \left\{\langle C_1, P(u_1^+, v_1^+)\rangle, \langle C_2, P(u_2^+, v_2^+)\rangle, \ldots, \langle C_n, P(u_n^+, v_n^+)\rangle\right\} \tag{15}$$

$$x^- = \left\{C_j, \min_i\langle s(C_j(x_i))\rangle | j = 1, 2, \ldots, n\right\} = \left\{\langle C_1, P(u_1^-, v_1^-)\rangle, \langle C_2, P(u_2^-, v_2^-)\rangle, \ldots, \langle C_n, P(u_n^-, v_n^-)\rangle\right\} \tag{16}$$

*Step 3* Thirdly, distances from Pythagorean fuzzy PIS and NIS are determined using Eqs. (17, 18) as follows:

$$D(x_i, x^+) = \sum_{j=1}^{n} w_j d(C_j(x_i), C_j(x^+)) = \frac{1}{2}\sum_{j=1}^{n} w_j \left( \left|(\mu_{ij})^2 - (\mu_j^+)^2\right| + \left|(v_{ij})^2 - (v_j^+)^2\right| + \left|(\pi_{ij})^2 - (\pi_j^+)^2\right| \right) \quad (17)$$

$$D(x_i, x^-) = \sum_{j=1}^{n} w_j d(C_j(x_i), C_j(x^-)) = \frac{1}{2}\sum_{j=1}^{n} w_j \left( \left|(\mu_{ij})^2 - (\mu_j^-)^2\right| + \left|(v_{ij})^2 - (v_j^-)^2\right| + \left|(\pi_{ij})^2 - (\pi_j^-)^2\right| \right) \quad (18)$$

for Eqs. (17, 18) $i = 1,2,\ldots,n$. In general, the smaller $D(x_i, x^+)$ the better the alternative $x_i$ and the bigger $D(x_i, x^-)$ the better the alternative $x_i$ and let $D_{\min}(x_i, x^+) = \min_{1 \le i \le m} D(x_i, x^+)$ and $D_{\max}(x_i, x^-) = \max_{1 \le i \le m} D(x_i, x^-)$.

*Step 4* Fourthly, the revised closeness $\xi(x_i)$ of the alternative $x_i$ is computed using Eq. (19) as follows:

$$\xi(x_i) = \frac{D(x_i, x^-)}{D_{\max}(x_i, x^-)} - \frac{D(x_i, x^+)}{D_{\min}(x_i, x^+)} \quad (19)$$

*Step 5* Finally, the best ranking order of the alternatives is determined. The alternative with the highest revised coefficient value is the best alternative.

### 4.1 PFAHP–PFTOPSIS-integrated model proposal for evaluating hospital service quality

The PFAHP–PFTOPSIS-integrated model proposal consists of several steps as shown in Fig. 1. First, the hospital service quality criteria and their sub-criteria are structured hierarchically according to the literature and hospital environments. After constructing the evaluation criteria hierarchy, the criteria weights are computed by applying interval-valued PFAHP method. Then, PFTOPSIS method is conducted to achieve the final ranking results. Finally, a broad discussion is presented in terms of showing how each hospital perform in terms of the handled criteria both independently of each other and all together using circumference of centroids method and area of expertise-based evaluation procedure. The detailed descriptions of each step are explained in each of the following sub-section.

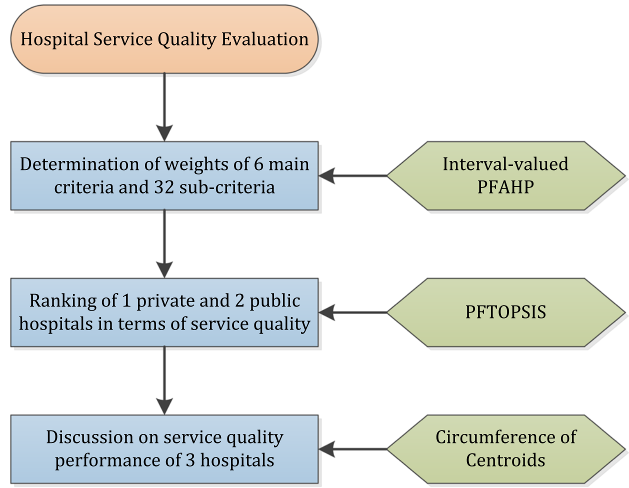


**Fig. 1** Framework of the PFAHP–PFTOPSIS-integrated model proposal

## 5 Case study: healthcare service quality evaluation in public and private hospitals

### 5.1 Hierarchical structure of hospital service quality evaluation criteria

The hierarchical structure of the hospital service quality evaluation criteria is described based on a detailed overview of the relevant literature (Chang 2014; Akdag et al. 2014; Taşkin et al. 2015). In addition to the related literature, the main and sub-criteria of hospital service quality is finalized by the aid of consultation involving healthcare managers, experts and academicians. In the lights of all these, the structure is constructed under six main criteria and 32 sub-criteria as shown in Fig. 2.

### 5.2 Linguistic scales and their corresponding fuzzy numbers

In this study, we benefit two linguistic scales and their corresponding fuzzy numbers. First, in evaluating service quality main and sub-criteria using pairwise comparison of PFAHP, we use the scale proposed by Ilbahar et al. (2018). That scale is based on interval-valued Pythagorean fuzzy numbers (Table 1). Second, in evaluating hospitals with respect to service quality criteria using PFTOPSIS, we apply the scale of Pérez-Domínguez et al. (2018). In Pérez-Domínguez et al. (2018), a nine-point Pythagorean fuzzy linguistic scale is defined as a set of linguistic variables which can be represented as Pythagorean fuzzy numbers. The prioritization of hospitals is performed by using five members' Pythagorean fuzzy linguistic scale (Table 2).

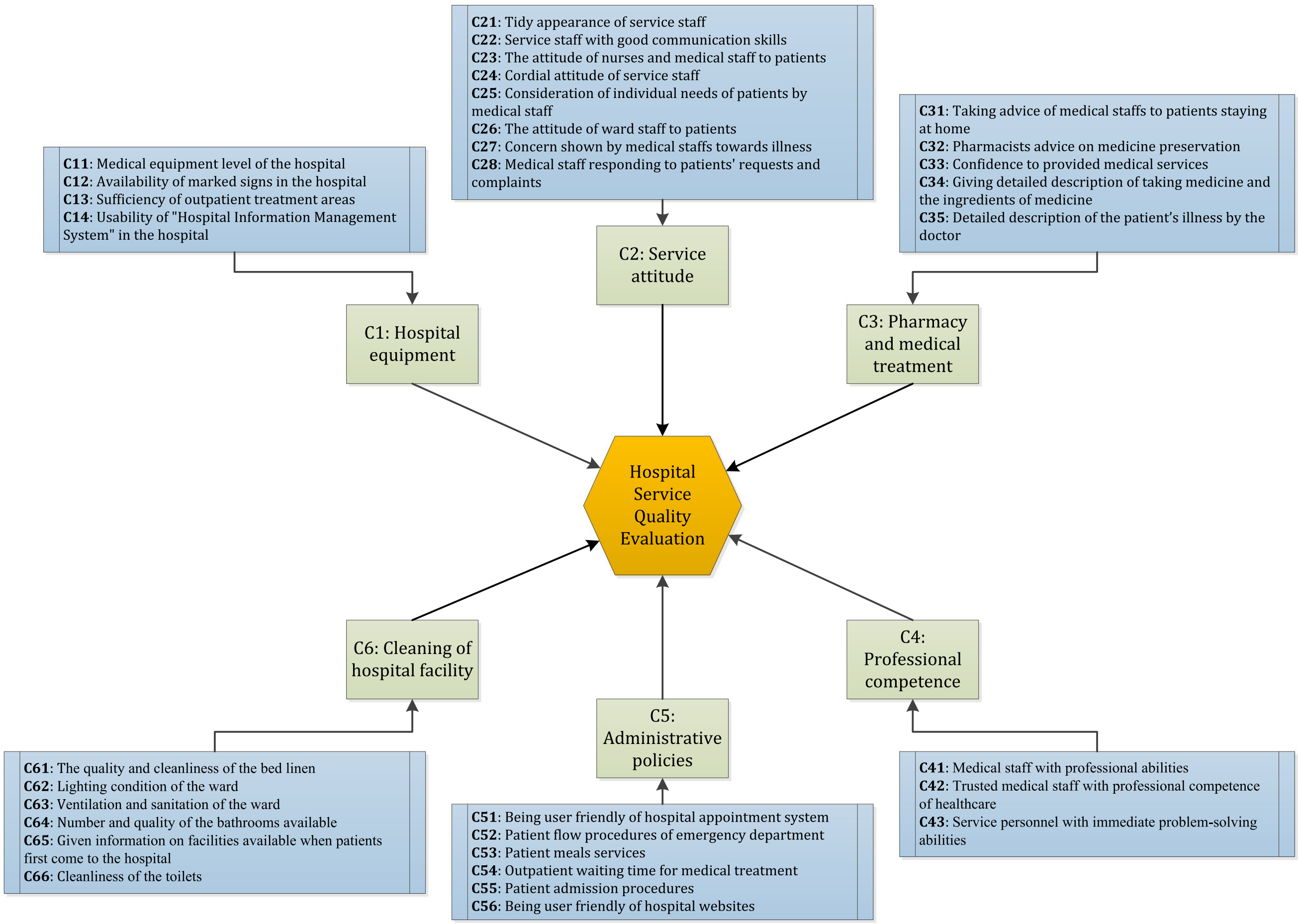


**Fig. 2** Hierarchical structure of hospital service quality evaluation criteria

**Table 2** Pythagorean fuzzy linguistic scale used in PFTOPSIS

| Linguistic term | Corresponding Pythagorean fuzzy number $(u,v)$ |
|---|---|
| Extremely low (EL) | (0.10,0.99) |
| Very little (VL) | (0.10,0.97) |
| Little (L) | (0.25,0.92) |
| Middle little (ML) | (0.40,0.87) |
| Middle (M) | (0.50,0.80) |
| Middle high (MH) | (0.60,0.71) |
| Big (B) | (0.70,0.60) |
| Very tall (VT) | (0.80,0.44) |
| Tremendously high (TH) | (0.10,0.00) |

## 5.3 Data collection process

This study is carried out in three hospitals located in Black Sea Region of Turkey, in 2018. While two of them are public hospitals that serve as education and research hospital in Turkey, one is a private hospital. The chosen alternatives are evaluated with respect to 32 evaluation criteria. These two public hospitals and one private hospital are selected due to their great reputation in the studied region. Two questionnaires have been circulated among the experts in order to (1) determine importance levels of hospital service quality criteria by using pairwise comparison of PFAHP method and (2) prioritize hospitals with respect to these criteria by using PFTOPSIS (Appendix). The first questionnaire has contained a total number of 6 main and 32 sub-criteria. Within the data collection process from the expert group, we contact a total of 38 evaluators (36 for the first questionnaire and 2 for the second questionnaire). From the conducted questionnaires, 32 of them (30 for the first questionnaire and 2 for the second questionnaire) are found valid and suitable for use in the study. The evaluation process takes about 2 weeks (from the end of January and the beginning of February, 2018). The expert group includes experts from medical, administrative and auxiliary services such as governmental medical department, hospital administration, quality deployment department, medical staff from emergency department, intensive care unit, audiometry, and other inpatient units

**Table 3** Expert team information

| Expert ID | Questionnaire type he/she filled | Experience (years) | Area of expertise: medical/ administrative/auxiliary services | Working department | Title |
|---|---|---|---|---|---|
| E1 | Questionnaire 1 | 16 | Medical | Intensive care unit | Medical assistant |
| E2 | Questionnaire 1 | 25 | Medical | Physical therapy department | Physiotherapist |
| E3 | Questionnaire 1 | 10 | Administrative | Administration | Assistant |
| E4 | Questionnaire 1 | 22 | Medical | Intensive care unit | Nurse |
| E5 | Questionnaire 1 | 10 | Administrative | Administration | Chef |
| E6 | Questionnaire 1 | 8 | Medical | X-ray department | X-ray technician |
| E7 | Questionnaire 1 | 24 | Medical | Intensive care unit | Nurse |
| E8 | Questionnaire 1 | 7 | Medical | Emergency department | Nurse |
| E9 | Questionnaire 1 | 3 | Medical | Laboratory | Laboratory assistant |
| E10 | Questionnaire 1 | 18 | Medical | General surgery | Nurse |
| E11 | Questionnaire 1 | 1 | Auxiliaries | Administration | Information technologies |
| E12 | Questionnaire 1 | 20 | Administrative | Administration | Chef |
| E13 | Questionnaire 1 | 1 | Medical | Audiology | Audiologist |
| E14 | Questionnaire 1 | 15 | Medical | Emergency department | Nurse |
| E15 | Questionnaire 1 | 25 | Administrative | Administration | Assistant manager |
| E16 | Questionnaire 1 | 4 | Administrative | Administration | Assistant manager |
| E17 | Questionnaire 1 | 7 | Medical | Audiology | Audiologist |
| E18 | Questionnaire 1 | 21 | Medical | Operating room | Assistant |
| E19 | Questionnaire 1 | 23 | Administrative | Administration | Assistant |
| E20 | Questionnaire 1 | 18 | Administrative | Administration | Coordinator |
| E21 | Questionnaire 1 | 4 | Auxiliaries | Administration | Secretary |
| E22 | Questionnaire 1 | 18 | Administrative | Administration | Assistant manager |
| E23-30 | Questionnaire 1 | – | Patient | – | – |
| E31 | Questionnaire 2 | 40 | Administrative | Administration | General director |
| E32 | Questionnaire 2 | 40 | Administrative | Administration | General director |

(doctor, nurse, technician, etc.) and ward service provider. Also, a number of patients are included to the first questionnaire as they are main stakeholders of hospitals. This additional questionnaire execution process takes about 10 days (last 10 days of October, 2018). These 32 evaluators are employers who are well experienced in the healthcare delivery and workflow in the hospitals. The information about the expert team and corresponding working experience is set out in Table 3. Due to anonymity reasons, experts' identity has not been revealed herein, and therefore, they have been demonstrated as E1, E2, … and E32.

## 5.4 Weighting calculation of main evaluation criteria and sub-criteria using PFAHP

Six main evaluation criteria including 32 sub-criteria are considered in this study to evaluate hospital service quality. Weighs for these 32 sub-criteria are obtained via PFAHP computations of 30 evaluators. The procedure explained in Sect. 3.2 shows the computational processes to derive the importance weights of evaluation criteria by using the proposed approach.

Thirty evaluators are asked to express their pairwise comparisons about the importance weight of each evaluation criterion by using the linguistic variables defined in Table 1. In this stage, the linguistic variables are transferred into corresponding interval-valued Pythagorean fuzzy numbers. Since the ratings of these evaluators are different, it is required to aggregate their subjective judgments toward a compromised pairwise comparison matrix A as indicated in Step 1 of Sect. 3.2. The aggregated compromised pairwise comparison matrix for the main criteria is given in Table 4. The difference matrix D and Interval multiplicative matrix S are also given in Tables 5 and 6, respectively.

The determinacy value matrix as stated in Eq. (11) and matrix of weights before normalization as in Eq. (12) are given in Tables 7 and 8, respectively.

Finally, the normalized priority weights of main criteria are computed using Eq. (13) as shown in Fig. 3. Due to space limitations, all of the computations related to the sub-

**Table 4** Aggregated compromised pairwise comparison evaluation of experts in matrix form

| Main criteria | Pythagorean fuzzy numbers: {[degree of membership],[degree of non-membership]} {[$\mu_L$,$\mu_U$],[$\nu_L$,$\nu_U$]} | | | | | |
|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 |
| C1 | {[0.197,0.197],[0.197,0.197]} | {[0.608,0.712],[0.288,0.362]} | {[0.462,0.558],[0.432,0.532]} | {[0.288,0.38],[0.603,0.708]} | {[0.615,0.722],[0.275,0.368]} | {[0.523,0.628],[0.372,0.467]} |
| C2 | {[0.288,0.362],[0.608,0.712]} | {[0.197,0.197],[0.197,0.197]} | {[0.425,0.532],[0.465,0.572]} | {[0.26,0.357],[0.623,0.74]} | {[0.513,0.622],[0.378,0.483]} | {[0.33,0.425],[0.562,0.67]} |
| C3 | {[0.432,0.532],[0.462,0.558]} | {[0.465,0.572],[0.425,0.532]} | {[0.197,0.197],[0.197,0.197]} | {[0.335,0.427],[0.557,0.662]} | {[0.592,0.703],[0.297,0.402]} | {[0.452,0.552],[0.442,0.545]} |
| C4 | {[0.603,0.708],[0.288,0.38]} | {[0.623,0.74],[0.26,0.357]} | {[0.557,0.662],[0.335,0.427]} | {[0.197,0.197],[0.197,0.197]} | {[0.672,0.808],[0.192,0.265]} | {[0.5,0.632],[0.365,0.46]} |
| C5 | {[0.275,0.368],[0.615,0.722]} | {[0.378,0.483],[0.513,0.622]} | {[0.297,0.402],[0.592,0.703]} | {[0.192,0.265],[0.672,0.808]} | {[0.197,0.197],[0.197,0.197]} | {[0.307,0.407],[0.64,0.66]} |
| C6 | {[0.372,0.467],[0.523,0.628]} | {[0.562,0.67],[0.33,0.425]} | {[0.442,0.545],[0.452,0.552]} | {[0.365,0.46],[0.5,0.632]} | {[0.64,0.66],[0.307,0.407]} | {[0.197,0.197],[0.197,0.197]} |

criteria weighting using PFAHP are not provided inside the paper.

Similarly, the local and global importance weights of sub evaluation criteria are listed in Table 9 following the PFAHP procedure as in weighting six main criteria.

Table 9 provides the importance weight and rank of each evaluation criterion assessed by 30 experts. The results show that the five most important criteria for evaluating hospital service quality are: medical staff with professional abilities (C41), medical equipment level of the hospital (C11), trusted medical staff with professional competence of healthcare (C42), service personnel with immediate problem-solving abilities (C43), and detailed description of the patient's illness by the doctor (C35). On the contrary, the five least important criteria are as follows: patient meals services (C53), being user friendly of hospital Web sites (C56), cordial attitude of service staff (C24), patient admission procedures (C55), and concern shown by medical staffs toward illness (C27).

## 5.5 Prioritization of hospitals using PFTOPSIS

Two evaluators who are experienced in healthcare management and know well of each of three hospitals use the linguistic variables defined in Table 2 to assess the service quality performance of the hospitals with respect to evaluation criteria. Since their evaluation ratings are different, their opinions are aggregated as Pythagorean fuzzy performance ratings of these five hospitals. The results are given in Table 10.

The linguistic variables are transformed into Pythagorean fuzzy numbers. This is the first stage of the FTOPSIS analysis (determination of Pythagorean fuzzy decision matrix). The weights of criteria which are computed in PFAHP stage are then added into the calculation in PFTOPSIS analysis. Using the formulas in steps 2–4 of PFTOPSIS algorithm, Pythagorean fuzzy PIS & NIS, distances from Pythagorean fuzzy PIS & NIS, and revised closeness values are calculated. The resulting closeness coefficients values of hospitals are reported in Table 11. According to the PFTOPSIS method, the hospital closest to 1 is the hospital which is the closest to the positive ideal solution, and the least close to the negative ideal solution. Thus, the hospital which has the biggest $\xi(X_i)$ value has performed best in terms of service quality. According to Table 11, Hospital 1 has shown the best performance.

## 5.6 Discussion

In this section, a discussion on evaluation of hospital alternatives with respect to 32 service quality criteria is presented. To make a critique for individual performance of 3 hospitals, nonfuzzy performance (BNP) service quality

**Table 5** The difference matrix

| Main criteria | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| C1 | {[0,0]} | {[0.239,0.423]} | {[− 0.07,0.125]} | {[− 0.419,− 0.22]} | {[0.243,0.445]} | {[0.056,0.257]} |
| C2 | {[− 0.423,− 0.239]} | {[0,0]} | {[− 0.146,0.066]} | {[− 0.48,− 0.261]} | {[0.03,0.243]} | {[− 0.34,− 0.135]} |
| C3 | {[− 0.125,0.07]} | {[− 0.066,0.146]} | {[0,0]} | {[− 0.326,− 0.128]} | {[0.189,0.407]} | {[− 0.093,0.109]} |
| C4 | {[0.22,0.419]} | {[0.261,0.48]} | {[0.128,0.326]} | {[0,0]} | {[0.381,0.617]} | {[0.038,0.266]} |
| C5 | {[− 0.445,− 0.243]} | {[− 0.243,− 0.03]} | {[− 0.407,− 0.189]} | {[− 0.617,− 0.381]} | {[0,0]} | {[− 0.342,− 0.244]} |
| C6 | {[− 0.257,− 0.056]} | {[0.135,0.34]} | {[− 0.109,0.093]} | {[− 0.266,− 0.038]} | {[0.244,0.342]} | {[0,0]} |

**Table 6** The interval multiplicative matrix

| Main criteria | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| C1 | {[1,1]} | {[2.285,4.315]} | {[0.787,1.542]} | {[0.236,0.468]} | {[2.311,4.653]} | {[1.214,2.427]} |
| C2 | {[0.232,0.438]} | {[1,1]} | {[0.604,1.258]} | {[0.191,0.406]} | {[1.109,2.317]} | {[0.309,0.628]} |
| C3 | {[0.648,1.271]} | {[0.795,1.657]} | {[1,1]} | {[0.325,0.643]} | {[1.919,4.074]} | {[0.725,1.458]} |
| C4 | {[2.135,4.245]} | {[2.466,5.248]} | {[1.555,3.079]} | {[1,1]} | {[3.727,8.414]} | {[1.142,2.506]} |
| C5 | {[0.215,0.433]} | {[0.432,0.902]} | {[0.245,0.521]} | {[0.119,0.268]} | {[1,1]} | {[0.307,0.43]} |
| C6 | {[0.412,0.824]} | {[1.593,3.236]} | {[0.686,1.379]} | {[0.399,0.876]} | {[2.325,3.253]} | {[1,1]} |

**Table 7** Determinacy value matrix ($T$)

| Main criteria | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| C1 | 1.000 | 0.816 | 0.805 | 0.801 | 0.797 | 0.799 |
| C2 | 0.816 | 1.000 | 0.787 | 0.781 | 0.787 | 0.795 |
| C3 | 0.805 | 0.787 | 1.000 | 0.802 | 0.782 | 0.798 |
| C4 | 0.801 | 0.781 | 0.802 | 1.000 | 0.764 | 0.772 |
| C5 | 0.797 | 0.787 | 0.782 | 0.764 | 1.000 | 0.903 |
| C6 | 0.799 | 0.795 | 0.798 | 0.772 | 0.903 | 1.000 |

**Table 8** Matrix of weights before normalization ($t$)

| Main criteria | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| C1 | 1.000 | 2.693 | 0.937 | 0.282 | 2.777 | 1.455 |
| C2 | 0.273 | 1.000 | 0.733 | 0.233 | 1.347 | 0.372 |
| C3 | 0.773 | 0.965 | 1.000 | 0.388 | 2.343 | 0.871 |
| C4 | 2.555 | 3.014 | 1.859 | 1.000 | 4.639 | 1.409 |
| C5 | 0.258 | 0.524 | 0.300 | 0.148 | 1.000 | 0.333 |
| C6 | 0.494 | 1.919 | 0.823 | 0.492 | 2.517 | 1.000 |

performance rating values of three hospitals are provided in Table 12 using *Circumference of Centroids* method. In transforming linguistic terms to trapezoidal fuzzy numbers scale for assessing hospitals with respect to service quality criteria, the five-point scale provided by Samantra et al. (2017) is used.

A generalized trapezoidal fuzzy number is defined as $\tilde{A} = (a, b, c, d; w)$. The Circumcenter $S_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ of the generalized trapezoidal fuzzy number is computed as in Eq. (20):

$$S_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left( \frac{a + 2b + 2c + d}{6}, \frac{(2a + b - 3c)(2d + c - 3b) + 5w^2}{12w} \right) \quad (20)$$

The ranking function of the trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ which maps the set of all fuzzy numbers to a set of real numbers is defined as: $R(\tilde{A}) = \sqrt{\bar{x}_0^2 + \bar{y}_0^2}$ where $R(\tilde{A})$ is the Euclidean distance from the circumcenter of the centroids and the original point.

From Table 12, it is stated that Hospital 1 has better service quality performances in: cordial attitude of service staff, consideration of individual needs of patients by medical staff, and taking advice of medical staff to patients staying at home. On the other hand, the sufficiency of outpatient treatment areas and concern taken by medical staff in terms of illness are the two worst service quality performance aspects.

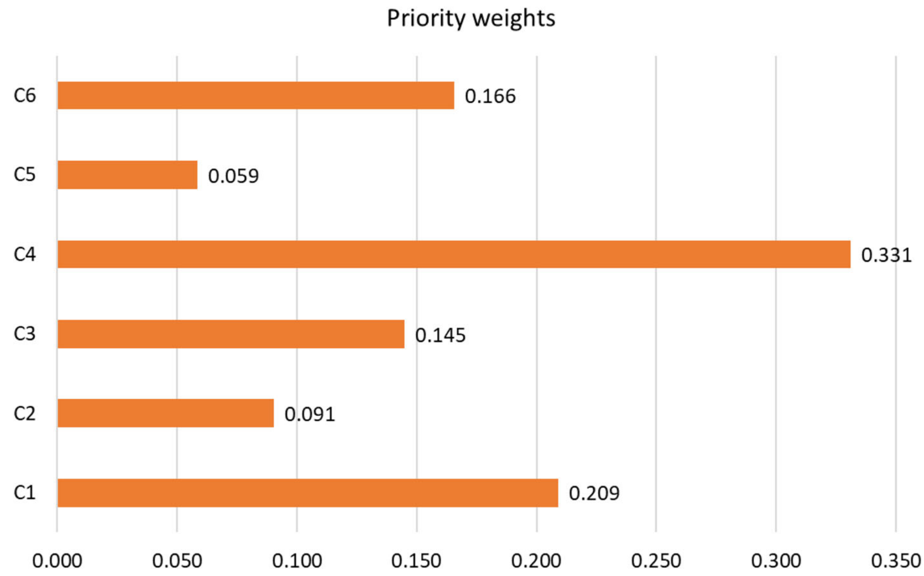


**Fig. 3** Priority weights of main criteria

Four best service aspects in Hospital 2 are: tidy appearance of service staff, the attitude of nurses and medical staff to patients, being user friendly of hospital Web sites, and number & quality of available bathrooms in the hospital. However, it is not well in medical personnel with immediate problem-solving abilities, medical equipment level of the hospital, confidence to provided medical services, being user friendly of hospital appointment system, and patient flow procedures of emergency department.

Hospital 3 has several service quality aspects that have same rating values such as availability of marked signs in the hospital, service staff with good communication skills, cordial attitude of service staff, consideration of individual needs of patients by medical staff, taking advice of medical staffs to patients staying at home, trusted medical staff with professional competence of healthcare, lighting condition of the ward, and number & quality of available bathrooms in the hospital. This hospital, however, still has two worst aspects: the quality and cleanliness of the bed linen and ventilation and sanitation of the ward.

When evaluated physical capacities of the hospitals, it has clearly stated that H1 has more space and medical resources than others. H1 Hospital is a public hospital and has 500 beds and 200 doctors. The second public hospital evaluated in this study is Hospital 3, and it serves with 300 beds and 83 doctors. The only private hospital "Hospital 2" serves with 105 beds and 42 doctors. As an overall evaluation, H1 hospital is a better position in providing service quality form the viewpoints of the health experts. The experts who evaluated these institutions with respect to the criteria are more experienced staff in their hospital.

This study also proved that service quality of public hospitals is better than that of private hospitals. Although private hospitals are rarely subsidized from governmental departments, and they must provide better services to retain patients' loyalty, innovations, and developments that the government has made in health in recent years have strengthened the serviceability of public hospitals. Unlike private hospitals, the operations budgets of public hospitals are mostly guaranteed by the governmental subsidization and taxpayers' tax. They have the financial and managerial power to provide health care at a good level.

As a creative contribution to this application case study, the weights of main and sub-criteria and ranking orders for different evaluation groups are analyzed. In this case study, evaluators have four main area of expertise as follows: (1) medical, (2) administrative, (3) auxiliary services, and (4) patient. For this aim, weights of main and sub-criteria are determined according to these four evaluator groups. Importance weights of hospital service quality criteria across four evaluation groups are given in Table 13.

On conclusion of analyzing the weight values and ranking orders of evaluation criteria for three evaluation groups (see Table 13), the medical staff group regards medical equipment level of the hospital (C11), medical staff with professional abilities (C41), and trusted medical staff with professional competence of healthcare (C42) as being more important than another evaluation criterion. Administrative staff group is more concerned about trusted medical staff with professional competence of healthcare (C42), medical staff with professional abilities (C41), and service personnel with immediate problem-solving abilities (C43). The auxiliary services staff group concludes three most important criteria which are: medical equipment level of the hospital (C11), service personnel with immediate problem-solving abilities (C43), and trusted medical staff with professional competence of healthcare (C42). Since the patients are among the stakeholders of hospitals, their

**Table 9** Importance weights of hospital service quality evaluation criteria

| Criteria | Local weight | Ranking order | Global weight | Ranking order |
|---|---|---|---|---|
| C1 | 0.209 | | | |
| C11 | 0.696 | 1 | 0.145 | 2 |
| C12 | 0.070 | 4 | 0.015 | 18 |
| C13 | 0.162 | 2 | 0.034 | 8 |
| C14 | 0.073 | 3 | 0.015 | 14 |
| C2 | 0.091 | | | |
| C21 | 0.107 | 6 | 0.010 | 27 |
| C22 | 0.154 | 3 | 0.014 | 21 |
| C23 | 0.168 | 1 | 0.015 | 13 |
| C24 | 0.088 | 8 | 0.008 | 30 |
| C25 | 0.107 | 5 | 0.010 | 26 |
| C26 | 0.120 | 4 | 0.011 | 24 |
| C27 | 0.101 | 7 | 0.009 | 28 |
| C28 | 0.154 | 2 | 0.014 | 19 |
| C3 | 0.145 | | | |
| C31 | 0.104 | 4 | 0.015 | 15 |
| C32 | 0.089 | 5 | 0.013 | 23 |
| C33 | 0.223 | 2 | 0.032 | 9 |
| C34 | 0.191 | 3 | 0.028 | 10 |
| C35 | 0.393 | 1 | 0.057 | 5 |
| C4 | 0.331 | | | |
| C41 | 0.449 | 1 | 0.149 | 1 |
| C42 | 0.361 | 2 | 0.119 | 3 |
| C43 | 0.191 | 3 | 0.063 | 4 |
| C5 | 0.059 | | | |
| C51 | 0.171 | 3 | 0.010 | 25 |
| C52 | 0.231 | 2 | 0.014 | 22 |
| C53 | 0.102 | 6 | 0.006 | 32 |
| C54 | 0.254 | 1 | 0.015 | 17 |
| C55 | 0.137 | 4 | 0.008 | 29 |
| C56 | 0.105 | 5 | 0.006 | 31 |
| C6 | 0.166 | | | |
| C61 | 0.233 | 2 | 0.039 | 7 |
| C62 | 0.084 | 6 | 0.014 | 20 |
| C63 | 0.133 | 3 | 0.022 | 11 |
| C64 | 0.125 | 4 | 0.021 | 12 |
| C65 | 0.090 | 5 | 0.015 | 16 |
| C66 | 0.335 | 1 | 0.056 | 6 |

viewpoint on importance weights of service quality criteria is very crucial. This group mostly concerns with medical equipment level of the hospital (C11), medical staff with professional abilities (C41), and detailed description of the patient's illness by the doctor (C35).

When the ranking orders of hospitals in terms of service quality performance are considered, it is concluded that Hospital 1 with the maximum of $\xi(X_i)$ has the best hospital service quality among these three hospitals from each of four evaluation group viewpoints. According to the viewpoints of medical, administrative staff and patients, while Hospital 2 stands in second place, and Hospital 3 is in third. Overall ranking orders of hospitals as shown in Table 11 give the same results with ranking orders from the viewpoint of three evaluator groups except auxiliary services staff group as shown in Table 14.

## 5.7 Comparative analysis

The integrated model is compared with the results of PFAHP–FTOPSIS (Gul and Ak 2018), PFAHP–FVIKOR

**Table 10** Aggregated Pythagorean fuzzy performance ratings of three hospitals

| Criteria | Hospital 1 | Hospital 2 | Hospital 3 |
|---|---|---|---|
| C11 | (0.375, 0.86) | (0.175, 0.955) | (0.25, 0.92) |
| C12 | (0.6, 0.7) | (0.375, 0.86) | (0.475, 0.76) |
| C13 | (0.25, 0.92) | (0.475, 0.76) | (0.25, 0.92) |
| C14 | (0.375, 0.86) | (0.25, 0.92) | (0.375, 0.86) |
| C21 | (0.6, 0.7) | (0.7, 0.6) | (0.375, 0.86) |
| C22 | (0.5, 0.8) | (0.5, 0.8) | (0.5, 0.8) |
| C23 | (0.475, 0.76) | (0.7, 0.6) | (0.3, 0.895) |
| C24 | (0.7, 0.6) | (0.375, 0.86) | (0.5, 0.8) |
| C25 | (0.7, 0.6) | (0.4, 0.795) | (0.475, 0.76) |
| C26 | (0.5, 0.8) | (0.375, 0.86) | (0.375, 0.86) |
| C27 | (0.25, 0.92) | (0.25, 0.92) | (0.25, 0.92) |
| C28 | (0.6, 0.7) | (0.5, 0.8) | (0.375, 0.86) |
| C31 | (0.7, 0.6) | (0.375, 0.86) | (0.475, 0.76) |
| C32 | (0.475, 0.76) | (0.5, 0.8) | (0.3, 0.895) |
| C33 | (0.6, 0.7) | (0.175, 0.955) | (0.25, 0.92) |
| C34 | (0.475, 0.76) | (0.375, 0.86) | (0.375, 0.86) |
| C35 | (0.5, 0.8) | (0.25, 0.92) | (0.375, 0.86) |
| C41 | (0.475, 0.76) | (0.25, 0.92) | (0.375, 0.86) |
| C42 | (0.6, 0.7) | (0.375, 0.86) | (0.475, 0.76) |
| C43 | (0.375, 0.86) | (0.1, 0.99) | (0.375, 0.86) |
| C51 | (0.475, 0.76) | (0.175, 0.955) | (0.375, 0.86) |
| C52 | (0.475, 0.76) | (0.175, 0.955) | (0.375, 0.86) |
| C53 | (0.5, 0.8) | (0.475, 0.76) | (0.25, 0.92) |
| C54 | (0.4, 0.795) | (0.6, 0.7) | (0.3, 0.895) |
| C55 | (0.375, 0.86) | (0.3, 0.895) | (0.375, 0.86) |
| C56 | (0.375, 0.86) | (0.7, 0.6) | (0.25, 0.92) |
| C61 | (0.375, 0.86) | (0.475, 0.76) | (0.175, 0.955) |
| C62 | (0.6, 0.7) | (0.6, 0.7) | (0.5, 0.8) |
| C63 | (0.375, 0.86) | (0.6, 0.7) | (0.175, 0.955) |
| C64 | (0.375, 0.86) | (0.7, 0.6) | (0.5, 0.8) |
| C65 | (0.25, 0.92) | (0.6, 0.7) | (0.175, 0.955) |
| C66 | (0.375, 0.86) | (0.6, 0.7) | (0.25, 0.92) |

**Table 11** PFTOPSIS $\xi(X_i)$ values

| Hospital | $D(X_i,X^+)$ | $D(X_i,X^-)$ | $\xi(X_i)$ | Ranking order |
|---|---|---|---|---|
| Hospital 1 | 0.0590 | 0.3467 | 0.000 | 1 |
| Hospital 2 | 0.1698 | 0.2683 | − 2.104 | 2 |
| Hospital 3 | 0.1849 | 0.2488 | − 2.415 | 3 |

(Gul 2018), PFAHP–PFVIKOR, and PFAHP–PFMOORA (Mete 2018) as given in Table 15.

The first comparison analysis is conducted between the integrated model and PFAHP–FTOPSIS model (Gul and Ak 2018). In evaluation of hospitals with respect to the criteria, usual trapezoidal fuzzy numbers-based TOPSIS is used unlike the current study. The comparison shows that, the ranking orders of hospitals are partially different from the integrated model. The ranking orders of Hospital 2 and Hospital 3 are different. It has the same result with PFAHP–PFTOPSIS model under auxiliary services staff's point of view.

The second comparison is performed between the current model and PFAHP–FVIKOR (Gul 2018). It has resulted in the same output (ranking orders of hospitals) with PFAHP–FTOPSIS model (Gul and Ak 2018). The third and fourth comparisons are regarding Pythagorean fuzzy sets-based approaches like our current approach.

**Table 12** BNP service quality performance rating values of three hospitals

| Criteria | Hospital 1 | Hospital 2 | Hospital 3 |
|---|---|---|---|
| C11 | 0.6776 | 0.5284 | 0.5993 |
| C12 | 0.8480 | 0.6776 | 0.7610 |
| C13 | 0.5993 | 0.7610 | 0.5993 |
| C14 | 0.6776 | 0.5993 | 0.6776 |
| C21 | 0.8480 | 0.9376 | 0.6776 |
| C22 | 0.7610 | 0.7610 | 0.7610 |
| C23 | 0.7610 | 0.9376 | 0.5993 |
| C24 | 0.9376 | 0.6776 | 0.7610 |
| C25 | 0.9376 | 0.6776 | 0.7610 |
| C26 | 0.7610 | 0.6776 | 0.6776 |
| C27 | 0.5993 | 0.5993 | 0.5993 |
| C28 | 0.8480 | 0.7610 | 0.6776 |
| C31 | 0.9376 | 0.6776 | 0.7610 |
| C32 | 0.7610 | 0.7610 | 0.5993 |
| C33 | 0.8480 | 0.5284 | 0.5993 |
| C34 | 0.7610 | 0.6776 | 0.6776 |
| C35 | 0.7610 | 0.5993 | 0.6776 |
| C41 | 0.7610 | 0.5993 | 0.6776 |
| C42 | 0.8480 | 0.6776 | 0.7610 |
| C43 | 0.6776 | 0.4682 | 0.6776 |
| C51 | 0.7610 | 0.5284 | 0.6776 |
| C52 | 0.7610 | 0.5284 | 0.6776 |
| C53 | 0.7610 | 0.7610 | 0.5993 |
| C54 | 0.6776 | 0.8480 | 0.5993 |
| C55 | 0.6776 | 0.5993 | 0.6776 |
| C56 | 0.6776 | 0.9376 | 0.5993 |
| C61 | 0.6776 | 0.7610 | 0.5284 |
| C62 | 0.8480 | 0.8480 | 0.7610 |
| C63 | 0.6776 | 0.8480 | 0.5284 |
| C64 | 0.6776 | 0.9376 | 0.7610 |
| C65 | 0.5993 | 0.8480 | 0.5284 |
| C66 | 0.6776 | 0.8480 | 0.5993 |

**Table 13** Weights of hospital service quality criteria across four evaluation groups

| Criteria | Local weight | | | | Global weight | | | |
|---|---|---|---|---|---|---|---|---|
| | MS viewpoint | AS viewpoint | AUS viewpoint | Patient viewpoint | MS viewpoint | AS viewpoint | AUS viewpoint | Patient viewpoint |
| C1 | 0.264 | 0.151 | 0.220 | 0.185 | | | | |
| C11 | 0.681 [1] | 0.662 [1] | 0.761 [1] | 0.667 [1] | 0.18 [1] | 0.016 [18] | 0.168 [1] | 0.123 [1] |
| C12 | 0.062 [4] | 0.057 [4] | 0.1 [2] | 0.1 [3] | 0.016 [14] | 0.012 [23] | 0.022 [11] | 0.018 [15] |
| C13 | 0.18 [2] | 0.145 [2] | 0.055 [4] | 0.199 [2] | 0.048 [7] | 0.067 [4] | 0.012 [18] | 0.037 [9] |
| C14 | 0.077 [3] | 0.137 [3] | 0.084 [3] | 0.034 [4] | 0.02 [11] | 0.009 [27] | 0.018 [13] | 0.006 [27] |
| C2 | 0.101 | 0.103 | 0.09 | 0.054 | | | | |
| C21 | 0.15 [2] | 0.056 [8] | 0.112 [4] | 0.101 [7] | 0.015 [16] | 0.009 [26] | 0.01 [20] | 0.006 [29] |
| C22 | 0.146 [3] | 0.161 [2] | 0.073 [8] | 0.164 [2] | 0.015 [17] | 0.027 [8] | 0.007 [29] | 0.009 [21] |
| C23 | 0.183 [1] | 0.157 [3] | 0.144 [2] | 0.146 [3] | 0.018 [13] | 0.026 [9] | 0.013 [17] | 0.008 [23] |
| C24 | 0.123 [4] | 0.076 [7] | 0.101 [6] | 0.054 [8] | 0.012 [22] | 0.013 [22] | 0.009 [23] | 0.003 [31] |
| C25 | 0.106 [6] | 0.114 [5] | 0.104 [5] | 0.107 [6] | 0.011 [25] | 0.019 [15] | 0.009 [22] | 0.006 [28] |
| C26 | 0.112 [5] | 0.122 [4] | 0.113 [3] | 0.13 [4] | 0.011 [24] | 0.02 [13] | 0.01 [19] | 0.007 [25] |
| C27 | 0.092 [7] | 0.087 [6] | 0.085 [7] | 0.123 [5] | 0.009 [28] | 0.015 [20] | 0.008 [27] | 0.007 [26] |
| C28 | 0.088 [8] | 0.226 [1] | 0.268 [1] | 0.175 [1] | 0.009 [29] | 0.038 [6] | 0.024 [9] | 0.01 [20] |
| C3 | 0.145 | 0.078 | 0.129 | 0.240 | | | | |
| C31 | 0.068 [5] | 0.137 [4] | 0.276 [3] | 0.103 [4] | 0.01 [26] | 0.011 [24] | 0.036 [6] | 0.025 [12] |
| C32 | 0.082 [4] | 0.1 [5] | 0.062 [5] | 0.086 [5] | 0.012 [23] | 0.008 [30] | 0.008 [26] | 0.021 [14] |
| C33 | 0.257 [2] | 0.26 [2] | 0.308 [1] | 0.133 [3] | 0.037 [8] | 0.02 [14] | 0.04 [5] | 0.032 [10] |
| C34 | 0.184 [3] | 0.188 [3] | 0.109 [4] | 0.209 [2] | 0.027 [10] | 0.015 [19] | 0.014 [16] | 0.05 [7] |
| C35 | 0.408 [1] | 0.316 [1] | 0.244 [2] | 0.47 [1] | 0.059 [4] | 0.025 [11] | 0.032 [8] | 0.113 [3] |
| C4 | 0.292 | 0.442 | 0.406 | 0.253 | | | | |
| C41 | 0.502 [1] | 0.39 [2] | 0.255 [3] | 0.473 [1] | 0.147 [2] | 0.172 [2] | 0.103 [4] | 0.119 [2] |
| C42 | 0.308 [2] | 0.406 [1] | 0.356 [2] | 0.381 [2] | 0.09 [3] | 0.18 [1] | 0.145 [3] | 0.096 [4] |
| C43 | 0.189 [3] | 0.204 [3] | 0.389 [1] | 0.146 [3] | 0.055 [5] | 0.09 [3] | 0.158 [2] | 0.037 [8] |
| C5 | 0.057 | 0.058 | 0.063 | 0.05 | | | | |
| C51 | 0.224 [2] | 0.141 [4] | 0.078 [5] | 0.143 [4] | 0.013 [20] | 0.008 [29] | 0.005 [31] | 0.007 [24] |
| C52 | 0.168 [3] | 0.165 [2] | 0.518 [1] | 0.366 [1] | 0.01 [27] | 0.01 [25] | 0.033 [7] | 0.018 [16] |
| C53 | 0.119 [5] | 0.128 [5] | 0.096 [4] | 0.057 [6] | 0.007 [31] | 0.007 [31] | 0.006 [30] | 0.003 [32] |
| C54 | 0.247 [1] | 0.304 [1] | 0.131 [2] | 0.207 [2] | 0.014 [18] | 0.018 [16] | 0.008 [25] | 0.01 [19] |
| C55 | 0.132 [4] | 0.111 [6] | 0.12 [3] | 0.16 [3] | 0.008 [30] | 0.006 [32] | 0.008 [28] | 0.008 [22] |
| C56 | 0.109 [6] | 0.15 [3] | 0.057 [6] | 0.068 [5] | 0.006 [32] | 0.009 [28] | 0.004 [32] | 0.003 [30] |
| C6 | 0.141 | 0.167 | 0.092 | 0.219 | | | | |
| C61 | 0.22 [2] | 0.198 [2] | 0.173 [3] | 0.296 [2] | 0.031 [9] | 0.033 [7] | 0.016 [14] | 0.065 [6] |
| C62 | 0.09 [6] | 0.079 [6] | 0.092 [6] | 0.079 [5] | 0.013 [21] | 0.013 [21] | 0.008 [24] | 0.017 [17] |
| C63 | 0.112 [4] | 0.15 [3] | 0.157 [4] | 0.136 [3] | 0.016 [15] | 0.025 [10] | 0.014 [15] | 0.03 [11] |
| C64 | 0.137 [3] | 0.134 [4] | 0.104 [5] | 0.096 [4] | 0.019 [12] | 0.022 [12] | 0.01 [21] | 0.021 [13] |
| C65 | 0.097 [5] | 0.094 [5] | 0.214 [2] | 0.06 [6] | 0.014 [19] | 0.016 [17] | 0.02 [12] | 0.013 [18] |
| C66 | 0.343 [1] | 0.345 [1] | 0.26 [1] | 0.334 [1] | 0.048 [6] | 0.058 [5] | 0.024 [10] | 0.073 [5] |

Bracket [.] denotes the ranking order

*MS* medical staff, *AS* administrative staff, *AUS* auxiliary services staff

Two approaches yield same ranking orders in hospital service quality evaluation with our current approach. In addition, a Spearman correlation analysis is applied to measure the ratio correlation between the ranking orders of compared approaches. The outputs of correlation analysis are demonstrated in Table 16. According to this correlation analysis, there is a significant and positive correlation between the current model and others (50%, 50%, 100%, and 100%, respectively). Moreover, we have applied a Pearson correlation analysis between approaches using

**Table 14** PFTOPSIS scores and ranking orders in terms of four evaluation groups

| Hospital | $D(X_i,X^+)$ | $D(X_i,X^-)$ | $\xi(X_i)$ | Ranking order |
|---|---|---|---|---|
| MS viewpoint | | | | |
| Hospital 1 | 0.059 | 0.344 | 0.000 | 1 |
| Hospital 2 | 0.168 | 0.266 | − 2.102 | 2 |
| Hospital 3 | 0.183 | 0.247 | − 2.411 | 3 |
| AS viewpoint: | | | | |
| Hospital 1 | 0.074 | 0.351 | 0.000 | 1 |
| Hospital 2 | 0.166 | 0.284 | − 1.441 | 2 |
| Hospital 3 | 0.198 | 0.252 | − 1.958 | 3 |
| AUS viewpoint: | | | | |
| Hospital 1 | 0.035 | 0.365 | 0.000 | 1 |
| Hospital 2 | 0.203 | 0.246 | − 5.181 | 3 |
| Hospital 3 | 0.158 | 0.267 | − 3.824 | 2 |
| Patient viewpoint: | | | | |
| Hospital 1 | 0.065 | 0.3454 | 0.000 | 1 |
| Hospital 2 | 0.162 | 0.2741 | − 1.690 | 2 |
| Hospital 3 | 0.196 | 0.2438 | − 2.307 | 3 |

final scores of each approach. Results of this second correlation analysis are provided in Table 17.

According to results in Table 17, the relationships between ranking results are very strong. In VIKOR-based approaches, a higher index value shows a lower ranking order. Hence, the correlation coefficient between PFAHP–FVIKOR and PFAHP–PFVIKOR approaches and the remaining approaches is a negative, high value as shown in Table 17. The correlation coefficient between the proposed approach and PFAHP–PFMOORA approach is positive and the highest of all approaches (0.988). The lowest correlation coefficient values are obtained from PFAHP–FVIKOR with PFAHP–FTOPSIS (− 0.766 and 0.900). In sum, the proposed approach can produce reasonable results for evaluating hospital service quality using the advantage of Pythagorean fuzzy sets that reflects uncertainty in more powerful level than usual fuzzy sets. Considering the ranking results of the two compared Pythagorean fuzzy set-based approaches, it is proved that the proposed approach can provide suitable information to assist healthcare issues in the hospital services.

## 6 Conclusion

Measuring hospital service quality is one of the major concerns of healthcare industry over world. Since healthcare delivery in Turkey are provided in a very competitive environment, for making a better choice, the services delivered by the public and private hospitals should be evaluated according to the viewpoint of stakeholders such as medical staff, hospital executives, and auxiliary services personal in terms of satisfaction. In this study, a successful application of a hospital service quality evaluation approach including PFAHP and PFTOPSIS is presented. The case study is performed under fuzzy environment to reduce uncertainty and vagueness, and linguistic variables parameterized by Pythagorean fuzzy numbers are used. The proposed PFAHP–PFTOPSIS approach is separated from others with the integration of Pythagorean fuzzy sets, AHP and TOPSIS methods, in a way providing a systematic decision-making process. Through the case study, six main hospital service quality evaluation criteria and 32 sub-criteria are used to assess two public and one private hospitals in Turkey by two questionnaires filled by four expert groups called (1) medical staff, (2) administrative staff, (3) auxiliary services staff, and (4) patients. Results show that the five most important criteria for evaluating hospital service quality are: medical staff with professional abilities, medical equipment level of the hospital, trusted medical staff with professional competence of healthcare, service personnel with immediate problem-solving abilities, and cleanliness of the toilets. It is also proved that service quality of public hospitals discussed is better than that of private hospitals. An additional analysis is made in determination of the weights of main and sub-criteria and ranking orders for different evaluation groups. According to the each of four evaluation groups, medical equipment level of the hospital, medical staff with professional abilities, and trusted medical staff with professional competence of healthcare are regarded as being the most

**Table 15** Ranking results of the compared approaches

| Hospital | Ranking order | | | | |
|---|---|---|---|---|---|
| | Current model: PFAHP–PFTOPSIS | PFAHP–FTOPSIS | PFAHP–FVIKOR | PFAHP–PFVIKOR[a] | PFAHP–PFMOORA |
| Hospital 1 | 1 | 1 | 1 | 1 | 1 |
| Hospital 2 | 2 | 3 | 3 | 2 | 2 |
| Hospital 3 | 3 | 2 | 2 | 3 | 3 |

[a]It is noted that the result is based on $Q$ index of PFVIKOR and $v$ (maximum group utility) is set to 1

**Table 16** Spearman correlation coefficient results of the compared approaches

| Spearman's rho | | Current model: PFAHP–PFTOPSIS | PFAHP–FTOPSIS | PFAHP–FVIKOR | PFAHP–PFVIKOR | PFAHP–PFMOORA |
|---|---|---|---|---|---|---|
| Current model: PFAHP–PFTOPSIS | Correlation coefficient | 1.000 | 0.500 | 0.500 | 1.000** | 1.000** |
| | Sig. (2-tailed) | . | 0.667 | 0.667 | . | . |
| | *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–FTOPSIS | Correlation coefficient | 0.500 | 1.000 | 1.000** | 0.500 | 0.500 |
| | Sig. (2-tailed) | 0.667 | . | . | 0.667 | 0.667 |
| | *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–FVIKOR | Correlation coefficient | 0.500 | 1.000** | 1.000 | 0.500 | 0.500 |
| | Sig. (2-tailed) | 0.667 | . | . | 0.667 | 0.667 |
| | *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–PFVIKOR | Correlation coefficient | 1.000** | 0.500 | 0.500 | 1.000 | 1.000** |
| | Sig. (2-tailed) | . | 0.667 | 0.667 | . | . |
| | *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–PFMOORA | Correlation coefficient | 1.000** | 0.500 | 0.500 | 1.000** | 1.000 |
| | Sig. (2-tailed) | . | 0.667 | 0.667 | . | . |
| | *N* | 3 | 3 | 3 | 3 | 3 |

**. Correlation is significant at the 0.01 level (2-tailed)

**Table 17** Pearson correlation coefficient results of the compared approaches

| | Current model: PFAHP–PFTOPSIS | PFAHP–FTOPSIS | PFAHP–FVIKOR | PFAHP–PFVIKOR | PFAHP–PFMOORA |
|---|---|---|---|---|---|
| Pearson correlation analysis | | | | | |
| Current model: PFAHP–PFTOPSIS | | | | | |
| Correlation coefficient | 1 | 0.900 | − 0.766 | − 0.968 | 0.988 |
| Sig. (2-tailed) | | 0.287 | 0.445 | 0.161 | 0.100 |
| *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–FTOPSIS | | | | | |
| Correlation coefficient | 0.900 | 1 | − 0.970 | − 0.980 | 0.821 |
| Sig. (2-tailed) | 0.287 | | 0.157 | 0.127 | 0.387 |
| N | 3 | 3 | 3 | 3 | 3 |
| PFAHP–FVIKOR | | | | | |
| Correlation coefficient | − 0.766 | − 0.970 | 1 | 0.902 | − 0.656 |
| Sig. (2-tailed) | 0.445 | 0.157 | | 0.284 | 0.545 |
| *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–PFVIKOR | | | | | |
| Correlation coefficient | − 0.968 | − 0.980 | 0.902 | 1 | − 0.917 |
| Sig. (2-tailed) | 0.161 | 0.127 | 0.284 | | 0.261 |
| *N* | 3 | 3 | 3 | 3 | 3 |
| PFAHP–PFMOORA | | | | | |
| Correlation coefficient | 0.988 | 0.821 | − 0.656[1] | − 0.917 | 1 |
| Sig. (2-tailed) | 0.100 | 0.387 | 0.545 | 0.261 | |
| *N* | 3 | 3 | 3 | 3 | 3 |

important three evaluation criteria among others. Overall ranking orders of hospitals are found similar.

The contributions and strengths of the paper are threefold: (1) It presents a new integrated model proposal based on PFAHP and PFTOPSIS; (2) it offers an additional analysis in determination of the weights of main and sub-criteria and ranking orders across four evaluation groups; (3) by the aid of additional analysis results of the integrated model proposal, it can help any hospital apart from the observed hospitals in this case study to identify its own strengths and weaknesses in their services, and provide better information to allow executives to improve their own areas of weakness to further improve service quality. Four approaches are benchmarked with the proposed approach in terms of correlation in both ranking orders and final scores.

As a limitation of the study, relevant to the second stage of the model proposal, it is important to keep in mind that the other preference-based MCDM methods (ELECTRE, PROMETHEE, TODIM, etc.) and/or their extension through the usage of other fuzzy set types such as hesitant fuzzy sets and neutrosophic sets can be alternatively used for the future extensions of this study.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with animals performed by any of the authors.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

## Appendix: Hospital service quality evaluation questionnaire

This questionnaire is purely related to an academic research entitled "Hospital service quality evaluation: an integrated model based on Pythagorean fuzzy AHP and fuzzy TOPSIS", aiming at measuring the healthcare service quality level of hospitals. This survey is divided into two sections to explain how we acquire the weights of criteria and sub-criteria and ratings (performances) of hospitals. The first questionnaire is designed for evaluating the relative importance of hospital service quality criteria. The second questionnaire is for evaluating the ranking order of hospitals with respect to each criterion.

The pairwise comparisons in the evaluation forms of first questionnaire will take a considerable time of you. However, findings of this study will contribute to present a guide for the way of highlighting hospital service quality.

Thank you for your attention. Regards.

### General questions

Hospital name:

Working department:

Expertise area (medical/administrative/auxiliary):

Total time of experience (year):

### First questionnaire

Main criteria evaluation

| Pairwise comparison of a criterion versus another one | CLI Certainly low importance | VLI Very low importance | LI Low importance | BAI Below average importance | AI Average importance | AAI Above average importance | HI High importance | VHI Very high importance | CHI Certainly high importance |
|---|---|---|---|---|---|---|---|---|---|
| C1 versus C2 | | | | | | | | | |
| C1 versus C3 | | | | | | | | | |
| C1 versus C4 | | | | | | | | | |
| C1 versus C5 | | | | | | | | | |
| C1 versus C6 | | | | | | | | | |
| C2 versus C3 | | | | | | | | | |
| C2 versus C4 | | | | | | | | | |
| C2 versus C5 | | | | | | | | | |
| C2 versus C6 | | | | | | | | | |
| C3 versus C4 | | | | | | | | | |
| C3 versus C5 | | | | | | | | | |
| C3 versus C6 | | | | | | | | | |
| C4 versus C5 | | | | | | | | | |
| C4 versus C6 | | | | | | | | | |
| C5 versus C6 | | | | | | | | | |

Sub-criteria evaluation of C1

| Pairwise comparison of a criterion versus another one | CLI Certainly low importance | VLI Very low importance | LI Low importance | BAI Below average importance | AI Average importance | AAI Above average importance | HI High importance | VHI Very high importance | CHI Certainly high importance |
|---|---|---|---|---|---|---|---|---|---|
| C11 versus C12 | | | | | | | | | |
| C11 versus C13 | | | | | | | | | |
| C11 versus C14 | | | | | | | | | |
| C12 versus C13 | | | | | | | | | |
| C12 versus C14 | | | | | | | | | |
| C13 versus C14 | | | | | | | | | |

## Second questionnaire

Linguistic terms: Extremely low (EL), Very little (VL), Little (L), Middle little (ML)

Middle (M), Middle high (MH), Big (B), Very tall (VT), Tremendously high (TH)

| Hospital service quality criteria | Hospitals | | |
|---|---|---|---|
| | Hospital 1 | Hospital 2 | Hospital 3 |
| C11 | | | |
| C12 | | | |
| C13 | | | |
| C14 | | | |
| C21 | | | |
| C22 | | | |
| C23 | | | |
| C24 | | | |
| C25 | | | |
| C26 | | | |
| C27 | | | |
| C28 | | | |
| C31 | | | |
| C32 | | | |
| C33 | | | |
| C34 | | | |
| C35 | | | |
| C41 | | | |
| C42 | | | |
| C43 | | | |
| C51 | | | |
| C52 | | | |
| C53 | | | |
| C54 | | | |
| C55 | | | |
| C56 | | | |
| C61 | | | |
| C62 | | | |
| C63 | | | |
| C64 | | | |
| C65 | | | |
| C66 | | | |

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