

Hospital Service Quality Evaluation: A Fuzzy Preference Relation Approach

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Abstract—This paper proposes a fuzzy preference relation approach to evaluate the hospital service quality in Taiwan. Pairwise comparisons based on consistent reciprocal additive transitivity are utilized to derive the importance weights of evaluation criteria and to obtain the performance rating of feasible hospitals with respect to each criterion. By multiplying the importance weights of evaluation criteria, and the performance ratings of feasible hospitals, the service qualities of hospital are determined. An illustrative example elicited from 5 public hospitals in southern Taiwan is used to demonstrate the evaluation procedures of this proposed approach.

Keywords—hospital service quality; fuzzy preference relations; performance evaluation; consistent reciprocal additive transitivity

I. INTRODUCTION

In 1995, Taiwanese National Health Insurance program was put into practice, the residents enjoyed high quality but relatively cheaper medical care compared with the developed countries. Hospital care is an industry with the characteristics of highly specialized medical capability and close contact with many persons. The importance of medical service and quality leaves no room for doubt, since good or bad quality of medical treatments directly affect the survival possibility. Recently the request for hospital service quality is gaining momentum in the world [1]. To manage a hospital successfully, the primary goals are providing good medical service quality and meeting various kinds of demands for the patients then retaining as many customers as possible [2]. Hospital, like other commercial or non-profit organizations, uses resources to provide many types of services, which is a measure of output for health-care organizations [3]. At the end of 2010, there are 19,329 public and private medical care institutions in Taiwan, so it is very difficult and complicated for the government to manage them. In order to manage so many medical care institutions efficiently, comparative performance evaluation, usually evaluated with itself over time or by comparison with others in the same industry, is used as an essential resolution of the managerial control function [3]. There are papers discussing the hospital or medical care service quality evaluation problems. Andaleeb [4] compared the quality of services provided by private and public hospitals in urban Bangladesh. Li [5] explored the relationship between hospital quality management and service quality performance for a sample of US community hospitals using a path analytic model. Raju [6] examined the impact of service quality and marketing on financial performance in the hospital industry. Andaleeb [7] surveyed the service quality perceptions

and patient satisfaction of hospitals in a developing country. Li [8] identified strategic operations management decisions in the US community hospitals, showed their causal relationships, and identified their effects on hospital performance. Goldman [9] compared the quality of rural hospitals participating in a public reporting initiative to that of their urban counterparts using Hospital Compare, a new national database containing process measures. Tsai [10] used fuzzy hierarchy sensitive with Delphi method to evaluate hospital organization performance. Many critical factors are considered in the hospital service quality evaluation; so this issue is regarded as a multicriteria decision making problem. This study therefore proposes an analytic hierarchy framework based on the consistent fuzzy preference relations to evaluate the service quality of these medical care institutions. The next section will briefly discuss the consistent fuzzy preference relations. An analytic hierarchy framework based on the consistent reciprocal additive transitivity for evaluate hospital service quality is derived in Section III. In Section IV, an illustrative example is presented. Finally, discussion and conclusion are given in Section V.

II. CONSISTENT FUZZY PREFERENCE RELATIONS

The decision information is frequently represented with the system of preference relations in many decision-making approaches. Herrera-Viedma et al. [11] proposed the consistent fuzzy preference relations, with the ability which not only enables decision makers to express preferences over a set of alternatives with the least judgments, but also avoids checking the inconsistency in decision-making process. Wang and Parkan [12] investigated the aggregation of fuzzy preference relations with an application to broadband internet service selection. Wang and Chen [13] applied fuzzy linguistic preference relations to improve the inconsistency of fuzzy AHP. Chao and Chen [14] evaluated the criteria and effectiveness of distance e-learning with consistent fuzzy preference relations. Chang and Wang [15] measured the success possibility of implementing advanced manufacturing technology by utilizing the consistent fuzzy preference relations. Wang and Chang [16] applied the consistent fuzzy preference relations in predicting the success of knowledge management implementation. Wang and Chang [17] forecasted the probability of successful knowledge management by consistent fuzzy preference

relations. Wang and Chen [18] applied the consistent fuzzy preference relations to partnership selection. Wang and Lin [19] applied consistent fuzzy preference relations to select merger strategy for commercial banks in new financial environments. The following briefly describes some definitions and propositions discussed in [20-28].

Given $X = \{x_1, x_2, \dots, x_n, n \geq 2\}$ be a finite set of alternatives to be pairwise assessed by a finite set of experts ($E = \{e_1, e_2, \dots, e_m, m \geq 2\}$). We can assume that the experts' preferences toward the set of alternatives X may be expressed in the following ways [29]:

(1) **Multiplicative preference relation.** A multiplicative preference relation A on a set of alternatives X is indicated by a matrix $A \subset X \times X$, $A = (a_{ij})$, a_{ij} is the ratio of the preference degree of alternative x_i over alternative x_j , A is assumed multiplicative reciprocal, that is

$$a_{ij} \otimes a_{ji} = 1 \quad \forall i, j \in \{1, \dots, n\} \quad (1)$$

(2) **Additive fuzzy preference relation.** An expert's preferences on a set of alternatives X is denoted by a positive preference relation matrix $P \subset X \times X$, with membership function: $\mu_p: X \times X \rightarrow [0, 1]$, where $\mu_p(x_i, x_j) = p_{ij}$ indicates the ratio of the preference intensity of alternative x_i over alternative x_j . If $p_{ij} = \frac{1}{2}$ implies indifference between x_i and x_j ($x_i \sim x_j$), $p_{ij} = 1$ indicates x_i is absolutely preferred to x_j , $p_{ij} = 0$ indicates x_j is absolutely preferred to x_i . P is assumed additive reciprocal, given by

$$p_{ij} + p_{ji} = 1 \quad \forall i, j \in \{1, \dots, n\} \quad (2)$$

Suppose there is a set of alternatives being associated with a multiplicative preference relation $A = (a_{ij})$ with $a_{ij} \in [\frac{1}{9}, 9]$. Then the corresponding fuzzy preference relation $P = (p_{ij})$ with $p_{ij} \in [0, 1]$ to $A = (a_{ij})$ is defined as:

$$p_{ij} = g(a_{ij}) = \frac{1}{2}(1 + \log_9 a_{ij}) \quad (3)$$

A consistent fuzzy preference relation P^* on $X = \{x_1, x_2, \dots, x_n, n \geq 2\}$ from $n-1$ preference values $\{p_{12}, p_{23}, \dots, p_{n-1n}\}$ can be constructed as follow.

$$B = \{p_{ij}, i < j \wedge p_{ij} \notin \{p_{12}, p_{23}, \dots, p_{n-1n}\}\} \quad (4)$$

$$p_{ji} = \frac{j-i+1}{2} - p_{ii+1} - p_{i+1i+2} \dots - p_{j-1j} \quad (5)$$

$$a = |\min\{B \cup \{p_{12}, p_{23}, \dots, p_{n-1n}\}\}| \quad (6)$$

$$P = \{p_{12}, \dots, p_{n-1n}\} \cup B \cup \{1 - p_{12}, \dots, 1 - p_{n-1n}\} \cup -B \quad (7)$$

$$f: [-a, 1+a] \rightarrow [0, 1], \quad f(x) = \frac{x+a}{1+2a} \quad (8)$$

III. FRAMEWORK TO EVALUATE HOSPITAL SERVICE QUALITY BY USING FUZZY PREFERENCE RELATIONS

This section proposes an analytic hierarchy model based on fuzzy preference relations to evaluate the hospital service quality. The procedures consist of: determining the importance weights of evaluation criteria, evaluating the performance rating of feasible hospitals with respect to each criterion, and ranking the alternative hospitals.

A. Identify the evaluation criteria for hospital service quality

The evaluation criteria are derived through literature review [2], widespread investigation and consultation with several experts. They are: **hospital environment** (C_1 : well-equipped medical equipment, warm and comfortable environment in the hospital, clear marked signs in the hospital); **service attitude** (C_2 : tidy appearance of service personnel, service personnel with good communication skills, caring attitude of medical staff, cordial attitude of service personnel); **pharmacy treatment** (C_3 : pharmacist's advices on taking medicine, medicine preservation advices by pharmacists, feeling a sense of security when medical services are provided); **professional capability** (C_4 : medical staff with professional abilities, trusted medical staff with professional competence of health care, detailed description of the patient's condition by the medical doctor, service personnel with immediate problem-solving abilities) and **administrative policy** (C_5 : ease of use of hospital reservation system, operating procedures of the emergency room, exact outpatient locations guided by service personnel, patient meals services, outpatient drug-picking services, outpatient waiting time for medical treatment, processes of hospitalized services).

B. Determining the importance weight of evaluation criterion

This study provides the evaluators linguistic variables quantified in a scale of $[\frac{1}{9}, 9]$ to express their preferences toward the importance weights of evaluation criteria (see Table I) and the performance rating of feasible alternatives (see Table II) with respect to each criterion [30]. Fuzzy preference relations proposed by Herrera -Viedma et al. [11] are employed in this study since it constructs a complete preference relation matrix that has n elements with the least $(n-1)$ pairwise comparisons.

TABLE I
LINGUISTIC VARIABLES FOR THE IMPORTANCE WEIGHT OF CRITERIA

Definition	Intensity of importance
Equally important (EQ)	1
Weakly more important (WK)	3
Strongly more important (ST)	5
Very strongly more important (VS)	7
Absolutely more important (AB)	9
Intermediate values presenting compromise	2,4,6,8

TABLE II
LINGUISTIC VARIABLES FOR THE PERFORMANCE RATING OF
ALTERNATIVES

Definition	Intensity of importance
Medium good (M)	1
Fairly good (FG)	3
Good (G)	5
Very good (VG)	7
Absolutely good (AG)	9
Intermediate values presenting compromise	2,4,6,8

- (1) The evaluators ($E_k, k=1,2,\dots,m$) are asked which is the more important of each two adjoining evaluation criteria ($C_i, i=1,2,\dots,n$) for a set of $n-1$ preference values $\{a_{12}, a_{23}, \dots, a_{n-1n}\}$, for example

$$A^k = \begin{bmatrix} C_1 & C_2 & C_3 & \dots & C_n \\ C_1 & 1 & a_{12}^k & \times & \times \\ C_2 & \times & 1 & a_{23}^k & \times \\ C_3 & \times & \times & 1 & a_{34}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \times & \times & \times & 1 \end{bmatrix} \quad (9)$$

where a_{ij}^k denotes the preference intensity toward criterion i and criterion j assessed by k^{th} evaluator. The sign “ $\times$ ” indicates the remaining a_{ij}^k which can be obtained by inverse comparison methods.

- (2) Use Eq. (3) to transform the preference value $a_{ij}^k \in [\frac{1}{9}, 9]$ into $p_{ij}^k \in [0, 1]$. The remaining p_{ij}^k can be calculated using Eqs. (2) and (5). If this preference matrix contains any values that are not included in the interval $[0, 1]$, then a transformation function is required to preserve the reciprocity and additive transitivity, given by

$$f(p_{ij}^k) = \frac{p_{ij}^k + a}{1 + 2a}, \quad (10)$$

where $a = |\min\{p_{12}, p_{23}, \dots, p_{n-1n}\}|$

- (3) Utilize the method of average value to integrate the judgments of m evaluators, namely

$$p_{ij} = \frac{1}{m}(p_{ij}^1 + p_{ij}^2 + \dots + p_{ij}^m) \quad (11)$$

- (4) Use r_{ij} to indicate the normalized fuzzy preference value of each criterion, such as

$$r_{ij} = \frac{p_{ij}}{\sum_{i=1}^n p_{ij}}, \quad i, j = 1, 2, \dots, n \quad (12)$$

- (5) Given the σ_i denoting the importance weight of evaluation criterion i , the importance weight of which is obtained by

$$\sigma_i = \frac{\sum_{j=1}^n r_{ij}}{\sum_{i=1}^n \sum_{j=1}^n r_{ij}} \quad (13)$$

C. Evaluating the performance rating of feasible alternatives with respect to each criterion

The evaluators are invited to express their subjective judgments regarding the performance ratings of feasible alternatives ($A_u, u=1,2,\dots,t$) with respect to each criterion by using linguistic variables, as listed in Table II.

- (1) Under each criterion, the evaluators are asked to compare the performance rating of adjoining alternatives for a set of $t-1$ preference data $\{b_{12}, b_{23}, \dots, b_{t-1t}\}$, for example

$${}_i B = \begin{bmatrix} A_1 & A_2 & A_3 & \dots & A_t \\ A_1 & 1 & {}_i b_{12}^k & \times & \times \\ A_2 & \times & 1 & {}_i b_{23}^k & \times \\ A_3 & \times & \times & 1 & {}_i b_{34}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_t & \times & \times & \times & 1 \end{bmatrix} \quad (14)$$

where ${}_i b_{uv}^k$ represents the performance rating assessed by k^{th} evaluator for alternative A_u and alternative A_v with respect to evaluation criterion i .

- (2) Using Eq. (3), the performance rating ${}_i b_{uv}^k$ is transformed into ${}_i q_{uv}^k$ in a scale $[0, 1]$. If this preference matrix contains any values that are not included in the interval $[0, 1]$, then a transformation function is required, given by

$$f({}_i q_{uv}^k) = \frac{{}_i q_{uv}^k + a}{1 + 2a}, \quad (15)$$

where $a = |\min\{q_{12}, q_{23}, \dots, q_{t-1t}\}|$

- (3) Synthesize the different judgments of m evaluators, namely

$${}_i q_{uv} = \frac{1}{m}({}_i q_{uv}^1 + {}_i q_{uv}^2 + \dots + {}_i q_{uv}^m) \quad (16)$$

- (4) Take ${}_i \lambda_u$ to indicate the normalized performance rating of alternative A_u with respect to evaluation criterion i .

$${}_i \lambda_u = \frac{{}_i q_{uv}}{\sum_{u=1}^t \sum_{v=1}^t {}_i q_{uv}}, \quad u, v = 1, 2, \dots, t \quad (17)$$

D. Ranking the alternatives

Ranking the alternatives by the performance value Q which is defined as

$$Q_u = \sum_{i=1}^n {}_i \lambda_u \sigma_i \quad (18)$$

where ϖ_i is the importance weight of evaluation criterion i , and the best alternative is the one which has the largest performance value Q .

IV. EMPIRICAL ANALYSIS

This study chooses 4 public hospitals located in southern Taiwan to be evaluated by 5 evaluators according to 5 major evaluation criteria (including 21 sub-criteria). Analytic hierarchy selections based on the fuzzy preference relations are adopted to solve this multiple criteria performance evaluation problem. The computations of this proposed framework are described as follows.

A. Weighting calculation for evaluation criteria

Pairwise comparisons for these 5 major evaluation criteria are obtained via a series of interviews with 5 evaluators. The following examples clarify the computational process involved in obtaining the importance weights of evaluation criteria using the consistent fuzzy preference relations.

- (1) The pairwise comparison matrices derived from 5 evaluators for a set of 4 adjoining evaluation criteria $\{a_{12}, a_{23}, a_{34}, a_{45}\}$ are listed in Table III.

	E_1	E_2	E_3	E_4	E_5	
C_1	VT	LVS	LVS	LST	LAB	C_2
C_2	ST	AB	LST	VS	SW	C_3
C_3	LAB	LVLA	LAB	LVS	LVS	C_4
C_4	AB	VS	AB	AV	VS	C_5

- (2) Using Eq. (3) to transform the linguistic variables quantified in $[\frac{1}{9}, 9]$ listed in Table III into an interval $[0, 1]$, taking E_1 as an example and yielding the following values:

$$\begin{aligned} a_{12} &= VT = 6, & p_{12} &= (1 + \log_9 6)/2 = 0.908 \\ a_{23} &= LST = \frac{1}{5}, & p_{23} &= (1 + \log_9 \frac{1}{5})/2 = 0.134 \\ a_{34} &= LVS = \frac{1}{7}, & p_{34} &= (1 + \log_9 \frac{1}{7})/2 = 0.057 \\ a_{45} &= VS = 7, & p_{45} &= (1 + \log_9 7)/2 = 0.943 \end{aligned}$$

- (3) Using Eq. (11), the aggregated pairwise comparison matrix is obtained. The result is shown in Table IV.

	C_1	C_2	C_3	C_4	C_5
C_1	2.500	1.405	2.674	0.913	2.672
C_2	3.595	2.500	3.768	2.008	3.767
C_3	2.326	1.232	2.500	0.740	2.498
C_4	4.087	2.992	4.260	2.500	4.259

C_5	2.328	1.233	2.502	0.741	2.500
Total	14.836	9.362	15.704	6.902	15.696

- (4) The importance weight and rank of each evaluation criterion is then obtained by Eqs. (12) & (13), and the results are listed in Table V. Taking ϖ_1 as an example,

$$r_{11} = \frac{2.5}{2.5 + 3.595 + 2.326 + 4.087 + 2.328} = 0.169$$

$$\varpi_1 = \frac{0.169 + 0.150 + 0.286 + 0.132 + 0.170}{0.907 + 1.443 + 0.822 + 1.684 + 0.822} = 0.160$$

TABLE V
NORMALIZED MATRIX OF IMPORTANCE WEIGHT AND RANK OF EVALUATION CRITERIA

	C_1	C_2	C_3	C_4	C_5	Weight (ϖ_i)	Rank
C_1	0.169	0.150	0.286	0.132	0.170	0.160	3
C_2	0.242	0.267	0.403	0.291	0.240	0.254	2
C_3	0.157	0.132	0.267	0.107	0.159	0.145	5
C_4	0.275	0.320	0.455	0.362	0.271	0.297	1
C_5	0.157	0.132	0.267	0.107	0.159	0.145	4

The results show that the importance order of 5 evaluation criteria is: professional capability (0.297) > service attitude (0.254) > hospital environment (0.160) > administrative policy (0.145) > pharmacy treatment (0.145).

B. Calculation the performance rating of feasible hospitals with respect to criteria

The performance rating of 4 feasible hospitals is calculated as follows.

- (1) These 5 evaluators are interviewed to assess which hospital is better than another according to each evaluation criterion. The linguistic variables derived from Evaluator 1 are used as examples and listed in Table VI. The linguistic terms are translated into corresponding numbers, then into the interval $[\frac{1}{9}, 9]$ and finally in $[0, 1]$.
- (2) Since there are values in Table VII are not in the range of $[0, 1]$, this study uses Eq. (15) to transform the values. The transformed results are shown in Table VIII. We find that the absolute value of minimum in Table VII is 0.158, so the $f(q_{12}^1) = \frac{0.057 + 0.158}{1 + 2 * 0.158} = 0.163$.
- (3) Use Eq. (16) to aggregate the different evaluators' preference, the aggregated decision matrix is shown in Table IX.
- (4) Using Eq. (17) to normalize the performance rating of 4 feasible hospitals with respect to evaluation criteria. The results are listed in Table IX.

TABLE VI
EVALUATOR 1 PAIWISE COMPARES THE ALTERNATIVE IN CRITERION 1
WITH LINGUISTIC VARIABLES

	E_1	A1	A2	A3	A4
C_1	A1	X	LVG		
	A2		X	MF	
	A3			X	AG
	A4				X

TABLE VII
LINGUISTIC TERMS TRANSLATED INTO NUMBER

	E_1	A1	A2	A3	A4
C_1	A1	0.500	0.057	0.215	0.715
	A2	0.943	0.500	0.658	1.158
	A3	0.785	0.342	0.500	1.000
	A4	0.285	-0.158	0.000	0.500

TABLE IX
AGGREGATED AND NORMALIZED DECISION MATRIX

		A1	A2	A3	A4	NORM
C_1	A1	2.500	1.499	0.740	1.431	0.154
	A2	3.501	2.500	1.741	2.431	0.254
	A3	4.260	3.259	2.500	3.190	0.330
	A4	3.569	2.569	1.810	2.500	0.261
C_2	A1	2.500	3.393	1.921	2.653	0.262
	A2	1.607	2.500	1.029	1.760	0.172
	A3	3.079	3.971	2.500	3.231	0.320
	A4	2.347	3.240	1.769	2.500	0.246
C_3	A1	2.500	3.225	2.445	4.300	0.312
	A2	1.775	2.500	1.720	3.575	0.239
	A3	2.555	3.280	2.500	4.355	0.317
	A4	0.700	1.425	0.645	2.500	0.132
C_4	A1	2.500	2.804	2.450	2.807	0.264
	A2	2.196	2.500	2.146	2.502	0.234
	A3	2.550	2.854	2.500	2.856	0.269
	A4	2.193	2.498	2.144	2.500	0.233
C_5	A1	2.500	3.290	1.799	2.583	0.254
	A2	1.710	2.500	1.009	1.793	0.175
	A3	3.201	3.991	2.500	3.284	0.324
	A4	2.417	3.207	1.716	2.500	0.246

*NORM: Normalization value

TABLE VIII
TRANSFORMED NUMBERS

	E_1	A1	A2	A3	A4
C_1	A1	0.500	0.163	0.283	0.663
	A2	0.837	0.500	0.620	1.000
	A3	0.717	0.380	0.500	0.880
	A4	0.337	0.000	0.120	0.500

C. Ranking the performance degree of hospitals

Using Eq. (18) to multiply the importance weights of evaluation criteria by the performance ratings of feasible hospitals, an aggregative performance value Q_u for hospital

A_u is obtained. Generally speaking, the performance value is the-larger-the-better. Taking Q_3 as an example,

$$Q_3 = (0.160 \times 0.330) + (0.254 \times 0.320) + (0.145 \times 0.317) + (0.297 \times 0.269) + (0.145 \times 0.324) = 0.307$$

The performance values of 4 feasible hospitals are listed in Table X. The ranking of 4 hospitals is $Q_3 > Q_1 > Q_4 > Q_2$. The best hospital is A3.

TABLE X
PERFORMANCE VALUE AND RANK OF 4 HOSPITALS

	A1	A2	A3	A4
Q	0.251	0.214	0.307	0.228
Rank	2	4	1	3

V. CONCLUSION

Good service quality is a significant factor leads to the success of a hospital operation and management. The proposed approach is based on the reciprocal additive consistent fuzzy preference relations, rather than using conventional multiplicative preference relation. Namely, this method considers only $n-1$ pairwise comparisons, whereas the traditional AHP takes $\frac{n(n-1)}{2}$ judgments in a preference matrix with n elements, it is clear that the proposed approach is faster to execute and more efficient than the conventional pairwise comparison methods. According to the importance weights of evaluation criteria, the professional capability and service attitude are more important than other criteria. Furthermore, this proposed method is proved to be applicable in solving the multiple criteria decision making problems.

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