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Designing a model for healthcare services supply chain performance evaluation using neutrosophic multiple attribute decision-making technique

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Abstract

Healthcare services supply chain performance evaluation in hospitals that deal with society's well-being has significant importance on their performance improvement. The purpose of this research was to evaluate healthcare services supply chain performance using a neutrosophic multiple attribute decision-making technique in Tehran's hospitals. Comprehensive performance evaluation was conducted by applying both objective attributes that focused on the outcome along subjective attributes that were based on the judgment of evaluators. In this regard, neutrosophic logic has been deployed to face uncertainties in the expert's judgment for determining the priority of attributes over each other explained via linguistic variables in the form of trapezoidal neutrosophic numbers. Eigenvector-power as one of the multiple attribute decision-making techniques concerned with evaluating and choosing the best option among the available ones based on diverse and conflicting attributes was used to ascertain attributes' importance in addition to guaranteeing obtainment of the largest eigenvalue of the characteristic polynomial, has led to reduction of calculations. Neutrosophic algebraic operations embedded in the eigenvector-power technique after efficiency confirmation of the technique was acquired. In order to gap analysis, a paired t-test was exploited to discover the existence of differences between the current and desired performance of attributes. Then, attributes' weighted performance gaps were calculated by multiplying the weight of each attribute by its performance gap which smoothed attributes' performance gap criticality definition by applying quartiles. "Staff job satisfaction" and "response to demands" attributes were categorized as very highly critical, "treatment branding" and "proportion of service with cost" attributes were classified as highly critical, "technological comfort" and "stakeholder's interests" attributes were grouped as moderately critical and "access" and "treatment plan fulfilment" attributes were relegated as low critical, respectively according to the weighted performance gap.

Keywords: performance evaluation, healthcare services supply chain, multi attribute decision making, neutrosophic logic
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1 Introduction

Achieving high economic growth has always been one of the concerns of economic policymakers in developing countries, including Iran. To achieve this goal, special attention has been paid to the productivity of labor force, and health is one of the factors related to it. In the global competitiveness report, published annually by the World Economic Forum, health is one of the basic requirements of countries to achieve economic development [13]. In other words, since improving the health status of labor force is directly related to economic growth, it is important to provide health facilities for labor force by the government or private sector. In this regard, health and treatment services, and in its focus, hospitals and treatment centers, play a significant role in providing services [12]. Providing effective services to patients depends on the efficiency of the hospital supply chain in preparing optimal and timely medical care services, as well as supply and management of required medical items and equipment, in a way that can bring the hospital as a service enterprise to its material and spiritual goals [9]. Despite the capabilities of Iran's healthcare system, this system has always faced various obstacles, which affect its performance, however, many of these challenges are caused by a deficiency in the country's healthcare supply chain. Waiting to be admitted to hospital, interrupting treatment process due to lack of supply of required resources, low motivation of some treatment staff for continuous and patient care, and non-technology-oriented processes are some of the main reasons that cause problems in providing service and as a result endangering the health of patients [24]. These challenges show the vital role of supply chain management and the necessity of improving its performance in healthcare services, in such a way, it always requires continuous evaluation and management of its supply chain performance to improve its competitive advantage through the development of a performance evaluation system [15]. Service has four characteristics heterogeneity, inseparability, destructibility, and intangibility, which basically causes the nature of its supply chain to be different from the supply chain of production enterprises [6]. In production systems, there is a cycle of production-sale-consumption in which buyer and consumer are not necessarily the same, while in service systems, due to the inseparability of the service, there is a cycle of sales-production-consumption which buyer and consumer are almost the same [10]. Therefore, the supply chain of goods and services is common in some processes, but they are different from each other in other processes, and as a result, they need their adaptive performance evaluation model, and since conventional and widely used models are basically provided for manufacturing enterprises, therefore, the need to provide a new model to evaluate service supply chain performance is noticeable. In this regard, performance attributes and performance evaluation techniques were an integral part of this system, therefore, it is important to adopt a suitable mechanism for identifying performance attributes, as well as evaluating supply chain performance, in such a way, that its output can support managers in focusing on main decisions, determining performance gaps of the processes and exploiting appropriate corrective actions to improve the performance of the supply chain.

2 Literature review and research background

Previously, performance evaluation focused on financial measures such as return on investment, sales, profit, debt, and income. Given that traditional financial scales are not fully compatible with competencies of enterprises that require facing today's work environment, so financial scales have an old and outdated attitude focus [33]. On the other hand, traditional scales tend to focus on person or performance rather than on processes which provide a short-term vision and one-sided monitoring in such a way that it causes more concern than improvement [27]. This has led to creation of an integrated and balanced performance evaluation system at strategic, tactical, and operational levels and in this regard, supply chain performance evaluation provides feedback on its activities in terms of meeting expectations of stakeholders and goals attainment [3]. Supply chain managers of healthcare services in order to control performance and evaluate realization of supply chain strategies needs to define suitable performance attributes which help the enterprise to eliminate inadequacies in terms of prioritizing processes for allocating resources and focus on continuous improvement with the aim of restoring patient's health, which is considered ultimate goal and main focus of healthcare industry [29].

Multiple attribute decision making is an approach to evaluate and choose the best option among the available ones, based on diverse and conflicting attributes. Since, an option must be chosen from among available options in many decision making problems and also, various quantitative and qualitative attributes are involved which makes decision making difficult therefore, multiple attribute decision making techniques are exploited [8]. Several types of research have been carried out to evaluate healthcare services supply chain performance applying multiple attribute decision making techniques. Zulqarnain et al. [34] investigated supply chain performance in healthcare industry by testing effect of attributes on performance using the structural equation modeling method [34]. Tierney [28] weighted the attributes through a heuristic algorithm in order to analyze healthcare supply chain management performance and then the performance of hospitals was compared with each other exploiting an inference system [28]. Pfannstiel and

Rasche [21] in the hope of integrating approaches to measure sustainable supply chain performance, drew a balanced scorecard strategy map using multiple attribute decision making techniques based on cause and effect relationships between attributes [22]. Langabeer [16] prioritized the attributes with the intention of evaluating operating room supply chain performance exploiting multiple attribute decision making technique [16]. McConnell [18] in the interest of provide a framework for evaluating the performance of a sustainable service supply chain prioritized the attributes using multiple attribute decision making techniques [18]. Turner [30] for the purpose of supply chain performance evaluation ascertained attributes' weight based on opinion of experts in the form of a Likert scale and then ranking was done deploying multiple attribute decision making technique [30]. Sari and Suslu [23] weighted supply chain performance evaluation attributes applying multiple attribute decision making techniques with the aim of ranking a number of supply chains [23]. Abdullah et al. [2] in order to evaluate service supply chain environmental performance ranked hospitals based on attributes using multiple attribute decision making techniques [2]. Pfannstiel and Rasche [22] determined attributes and sub-attributes' weight in the hope of explaining a framework for the service supply chain performance measurement exploiting multiple attribute decision-making technique [21].

Non-deterministic approaches have been used with the intention of facing uncertainties considering each of them has some shortcomings. Neutrosophic logic has been introduced to the literature by Smarandache since fuzzy and intuitionistic fuzzy logics could only handle incomplete information, but not indeterminate and inconsistent information which exists commonly in these systems [14]. Neutrosophic theory means neutrosophy applied in many fields with the intention of solving problems related to indeterminacy. Locus of fuzzy, intuitionistic fuzzy and neutrosophic sets were depicted in figure 1 which implied comprehensiveness of neutrosophic logic in comparison to fuzzy and intuitionistic fuzzy logics. Line segment AB is locus of fuzzy set elements according to $\mu_A(x) + \nu_A(x) = 1$ which $\mu_A(x)$ and $\nu_A(x)$ are membership degree and non-membership degree of element A in set x, respectively. Triangle ABC is locus of intuitionistic fuzzy elements set according to $\mu_A(x) + \nu_A(x) + \pi_A(x) = 1$ which $\mu_A(x)$, $\nu_A(x)$ and $\pi_A(x)$ are membership degree, non-membership degree and indeterminacy degree of element A in set x, respectively. The Cube is locus of neutrosophic set elements according to $T_A(x) + I_A(x) + F_A(x) \leq 3$ which $T_A(x)$, $I_A(x)$ and $F_A(x)$ are truth membership degree, indeterminacy membership degree and falsehood membership degree of element A in set x, respectively. In this paper neutrosophic logic has been exploited so as to adopting a mechanism to face uncertainties in subjective judgments of experts which brings more accurate evaluation and more reliable results.

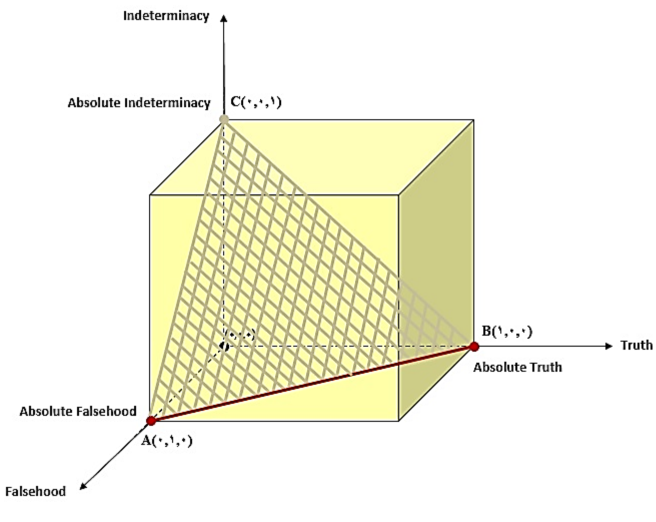

Figure 1: Locus of fuzzy, intuitionistic fuzzy and neutrosophic sets

3 Methods

3.1 Performance evaluation model

According to Stewart and Kenneth [25] the objective performance attribute focuses on the result, while subjective performance attribute is based on judgment of the evaluators. Objective attribute is proper for performance evaluation regardless of existing bias and prejudice in human subjective judgments whereas subjective attribute has ability to evaluate a part of the performance that is ignored by the objective attribute, which is called deficiency error [25]. In this regard, according to Asgharizadeh et al. [5] "proportion of service with cost", "technological comfort", "access", "response to demands", "stakeholder's interests" and "staff job satisfaction" were considered as subjective attributes and "treatment branding" and "treatment plan fulfilment" were considered as objective performance evaluation attributes for a comprehensive evaluation [5].

3.2 Attributes weight calculation

Data analysis in the interest of calculate attributes' weight was done using multiple attribute decision making techniques, numerical calculations, neutrosophic logic meanwhile MATLAB and Excel software was applied to perform the methods. The eigenvector as one of the common multiple attribute decision making techniques for attributes' weight determination applies pairwise comparison s to obtain the largest eigenvalue from characteristic equation [31]. Rising the number of attributes above three which is the same as dimensions of pairwise comparison s matrix causes power of the equation largest term to rise above three that makes it difficult and sometimes impossible to calculate roots of this polynomial equation exploiting direct methods. When the equation is so complex that it is not possible or cost-effective to use accurate direct methods to calculate the roots, then iterative methods of numerical analysis were exploited to obtain approximate solutions [4]. Power method, bracketing methods such as Bisection method and open methods such as Newton-Raphson and Secant methods are among the most important iterative methods used to calculate the eigenvalue in the eigenvector technique and have been compared with each other according to table 1. Based on this comparison, if the eigenvalue is calculated through the power method then besides guaranteeing to find the largest eigenvalue, it will reduce required calculations.

Table 1: Features of eigenvector and eigenvector-power techniques

	Eigenvector technique	Eigenvector-power technique
Eigenvalue calculation method	Numerical analysis*	Power method
Calculated eigenvalue	Not necessarily the largest value	The largest value
Guaranteeing convergence	It does not have	It has
Method accuracy	Approximation	Approximation
Guessing the initial solution	It needs to guess the initial solution in such a way that the closer it is to the final solution, the less number of iterations requires to be achieved	No need
The number of iterations until the eigenvalue was calculated	At least one iteration in both "perfect consistency" and "consistency" state of the pairwise comparison matrix**	-One iteration in perfect consistency state of pairwise comparison matrix -At least one iteration in consistency state of pairwise comparison matrix

* The three methods consisted of "Bisection", "Newton-Raphson" and "Secant" were deployed.
** The inconsistency ratio (ICR) in the "perfect consistency" state is zero, and in the "consistency" state is less than 0.1, respectively. It should be noted that if the inconsistency ratio is greater than 0.1 then pairwise comparisons will be invalid and need to be revised.

Pseudo code of eigenvector-power technique is according to algorithm 1.

Algorithm 1: Pseudo code of eigenvector-power technique

Input: U_0, A ; Output: $w_i(A)$

1. **set** $U_0 \leftarrow \begin{bmatrix} 1 \\ \dots \\ \dots \\ \dots \\ 1 \end{bmatrix}_{n\times 1}$
2. **set** $U_1 \leftarrow \frac{AU_0}{\|AU_0\|_\infty}$
3. **set** $\lambda_1 \leftarrow \frac{U_1^T AU_1}{U_1^T U_1}$
4. **set** $U_2 \leftarrow \frac{AU_1}{\|AU_1\|_\infty}$
5. **set** $\lambda_2 \leftarrow \frac{U_2^T AU_2}{U_2^T U_2}$
6. **while** $\left|\frac{\lambda_2-\lambda_1}{\lambda_2}\right| > \varepsilon$ **do**

7. **set** $\lambda_1 \leftarrow \lambda_2$

8. **set** $U_1 \leftarrow U_2$

9. **set** $U_2 \leftarrow \frac{AU_1}{\|AU_1\|_\infty}$

10. **set** $\lambda_2 \leftarrow \frac{U_2^T AU_2}{U_2^T U_2}$

11. **end while**

12. **set** $\lambda \leftarrow \lambda_1$

13. **set** $1 \leftarrow \sum_i w_i(A)$

14. **set** $\begin{bmatrix} 0 \\ \dots \\ \dots \\ \dots \\ 0 \end{bmatrix}_{n*1} \leftarrow (A{-}\lambda I)\, w_i(A)$

Eigenvalue was calculated through Bisection, Newton-Raphson, Secant, and eigenvector-power techniques for 100 random matrices of 4 to 8 dimensions in "perfect consistency" and "consistency" statuses in order to validate eigenvector-power technique. Then, comparison of the "mean number of iterations until the eigenvalue was achieved" and "standard deviation of the achieved eigenvalues" among the methods was done by coding and running in MATLAB version R2021b according to table 2. Validity of eigenvector-power technique was confirmed as the optimal method since values of the above two criteria for eigenvector-power technique were lower in comparison to those of other three methods due to faster and more accurate calculation.

Based on Figure 2, "mean number of iterations until the eigenvalue was calculated" and "standard deviation of the calculated eigenvalues" of eigenvector-power technique were lower compared to those of other methods in both "perfect consistency" and "consistency" states of the 4-8 dimensional pairwise comparison matrices.

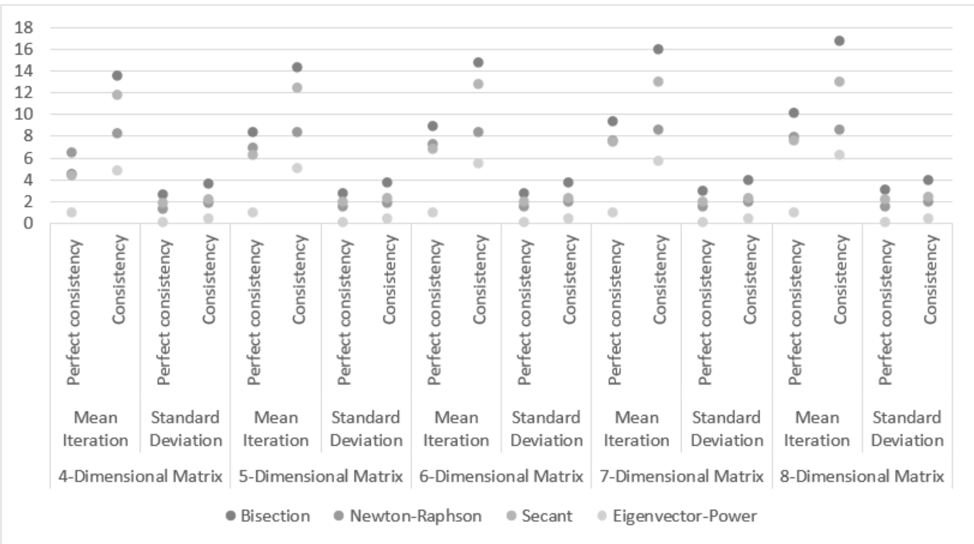

Figure 2: "Mean number of iterations until the eigenvalue was calculated" and "standard deviation of the calculated eigenvalues" comparison between the methods

After efficiency confirmation of eigenvector-power technique, the neutrosophic eigenvector-power technique was presented to face uncertainties in subjective judgments of experts ascertaining preference of attributes over each other through their pairwise comparisons. Therefore, neutrosophic algebraic operations were placed in eigenvector-power technique algorithm according to equations (3.1) to (3.8).

If $\tilde{p}{=}\langle (p_1, p_2, p_3, p_4)\,; \alpha_{\tilde{p}}, \theta_{\tilde{p}}, \beta_{\tilde{p}}\rangle$ and $\tilde{q}{=}\langle (q_1, q_2, q_3, q_4)\,; \alpha_{\tilde{q}}, \theta_{\tilde{q}}, \beta_{\tilde{q}}\rangle$ be two single-valued trapezoidal neutrosophic numbers, then:

Table 2: Number of iterations comparison between the methods

		Perfect consistency of pairwise comparison matrix				Consistency of pairwise comparison matrix			
		Bisection Method	Newton-Raphson Method	Secant Method	Eigenvector-Power Technique	Bisection Method	Newton-Raphson Method	Secant Method	Eigenvector-Power Technique
4-Dimensional Matrix	No. of iterations (Min)	1	1	1	1	1	1	1	1
	No. of iterations (Max)	13	12	8	1	17	7 13	12	5
	No. of iterations (Mean)	4.5	6.4	4.3	1	13.5	8.1	11.7	4.8
	S.D. of Eigen-value	2.5969	1.2340	1.7890	0	3.4942	1.7960	2.1690	0.2789
5-Dimensional Matrix	No. of iterations (Min)	1	1	1	1	1	1	1	1
	No. of iterations (Max)	16	14	13	1	17	14	13	6
	No. of iterations (Mean)	8.4	6.9	6.2	1	14.2	8.4	12.4	5
	S.D. of Eigen-value	2.6797	1.4496	1.8930	0	3.6627	1.8227	2.2065	0.2796
6-Dimensional Matrix	No. of iterations (Min)	1	1	1	1	1	1	1	1
	No. of iterations (Max)	16	14	13	1	17	15	13	6
	No. of iterations (Mean)	8.8	7.2	6.8	1	14.8	8.4	12.7	5.4
	S.D. of Eigen-value	2.7834	1.4552	1.9489	0	3.6900	1.8750	2.2850	0.2849
7-Dimensional Matrix	No. of iterations (Min)	1	1	1	1	1	1	1	1
	No. of iterations (Max)	16	15	12c	1	17	15	14	6
	No. of iterations (Mean)	9.3	7.6	7.4	1	15.8	8.5	12.9	5.6
	S.D. of Eigen-value	2.8776	1.4628	1.9533	0	3.7935	1.9158	2.2919	0.2968
8-Dimensional Matrix	No. of iterations (Min)	1	1	1	1	1	1	1	1
	No. of iterations (Max)	16	15	12	1	17	16	14	7
	No. of iterations (Mean)	10.1	7.8	7.6	1	16.7	8.5	12.9	6.2
	S.D. of Eigen-value	3.0728	1.5259	2.0386	0	3.8220	1.9617	2.3581	0.3107

Addition of the two numbers is in the form of following equation [1]:

$$\tilde{p}\oplus\tilde{q}=\langle(p_1+q_1,p_2+q_2,p_3+q_3,p_4+q_4)\,;\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{n}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\rangle \tag{3.1}$$

Subtraction of the two numbers is in the form of following equation [1]:

$$\tilde{p}\ominus\tilde{q}=\langle(p_1-q_4,p_2-q_3,p_3-q_2,p_4-q_1)\,;\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\rangle \tag{3.2}$$

Multiplication of the two numbers is in the form of following equation [1]:

$$\tilde{p}\otimes\tilde{q}=\begin{cases}\langle(p_1.q_1,p_2.q_2,p_3.q_3,p_4.q_4)\,;\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\rangle & if\;\; p_1>0,q_1>0\\ \langle(p_1.q_4,p_2.q_3,p_3.q_2,p_4.q_1)\,;\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\rangle & if\;\; p_4<0,q_1>0\\ \langle(p_4.q_4,p_3.q_3,p_2.q_2,p_1.q_1)\,;\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\rangle & if\;\; p_4<0,q_4<0\end{cases} \tag{3.3}$$

Division of the two numbers is in the form of following equation [1]:

$$\tilde{p}\oslash\tilde{q}=\begin{cases}\left\langle\left(\frac{p_1}{q_4},\frac{p_2}{q_3},\frac{p_3}{q_2},\frac{p_4}{q_1}\right);\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\right\rangle & if\;\; p_1>0,q_1>0\\ \left\langle\left(\frac{p_4}{q_4},\frac{p_3}{q_3},\frac{p_2}{q_2},\frac{p_1}{q_1}\right);\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\right\rangle & if\;\; p_4<0,q_1>0\\ \left\langle\left(\frac{p_4}{q_1},\frac{p_3}{q_2},\frac{p_2}{q_3},\frac{p_1}{q_4}\right);\alpha_{\tilde{p}}\wedge\alpha_{\tilde{q}},\theta_{\tilde{p}}\vee\theta_{\tilde{q}},\beta_{\tilde{p}}\vee\beta_{\tilde{q}}\right\rangle & if\;\; p_4<0,q_4<0\end{cases} \tag{3.4}$$

Inverse of the neutrosophic number is in the form of following equation [1]:

$$\tilde{p}^{-1} = \left\langle \left(\frac{1}{p_4}, \frac{1}{p_3}, \frac{1}{p_2}, \frac{1}{p_1} \right); \alpha_{\tilde{p}}, \theta_{\tilde{p}}, \beta_{\tilde{p}} \right\rangle \quad , \quad \tilde{p} \neq 0. \tag{3.5}$$

Multiplication of neutrosophic number by constant value is in the form of following equation [1]:

$$\Upsilon.\tilde{p} = \begin{cases} \langle (\Upsilon p_1, \Upsilon p_2, \Upsilon p_3, \Upsilon p_4); \alpha_{\tilde{p}}, \theta_{\tilde{p}}, \beta_{\tilde{p}} \rangle & if \quad \Upsilon > 0 \\ \langle (\Upsilon p_4, \Upsilon p_3, \Upsilon p_2, \Upsilon p_1); \alpha_{\tilde{p}}, \theta_{\tilde{p}}, \beta_{\tilde{p}} \rangle & if \quad \Upsilon < 0 \end{cases} \tag{3.6}$$

M^{th} root of the neutrosophic number is considered in the form of following equation:

$$\sqrt[m]{\tilde{p}} = \langle (\sqrt[m]{p_1}, \sqrt[m]{p_2}, \sqrt[m]{p_3}, \sqrt[m]{p_4}); \alpha_{\tilde{p}}, \theta_{\tilde{p}}, \beta_{\tilde{p}} \rangle \qquad if \quad (m = 2n+1) \quad or \quad (m = 2n \quad , \; p_1 \geq 0) \tag{3.7}$$

Neutrosophic number is deneutrosophicated exploiting following equation and becomes a crisp value [32]:

$$S(\tilde{p}) = \frac{1}{12}(p_1 + p_2 + p_3 + p_4).(2 + \alpha_{\tilde{p}} - \theta_{\tilde{p}} - \beta_{\tilde{p}}) \tag{3.8}$$

Preference of the performance evaluation attributes over each other explained via linguistic variables so trapezoidal neutrosophic numbers have been employed in the hope of express ambiguity in these variables. Table 3 lists the linguistic phrases used in this study along with the matching trapezoidal neutrosophic numerical values which are geometric mean of 20 expert's opinion.

Table 3: The linguistic phrases and corresponding trapezoidal neutrosophic numerical values

Linguistic phrase for paired comparisons	Numerical value
Same priority	$\langle(0.9, 1, 1, 1); 0.9, 0.1, 0.1\rangle$
Very low priority	$\langle(1.9, 2, 2, 2); 1, 0.1, 0\rangle$
Low priority	$\langle(3, 3, 3, 3.1); 0.8, 0.1, 0.2\rangle$
Relatively low priority	$\langle(3.9, 4, 4, 4); 0.9, 0, 0\rangle$
Moderate priority	$\langle(5, 5, 5, 5.1); 1, 0.1, 0\rangle$
Relatively high priority	$\langle(5.9, 6, 6, 6); 0.9, 0, 0.1\rangle$
High priority	$\langle(7, 7, 7, 7); 0.8, 0.2, 0.1\rangle$
Very high priority	$\langle(7.9, 8, 8, 8); 1, 0, 0\rangle$
Infinitely high priority	$\langle(8.9, 8.9, 9, 9); 0.9, 0.2, 0\rangle$

Notations that were used in the proposed algorithm were introduced in Table 4.

Table 4: Definitions of indexes

Notation	**Definition**
U_0	Default vector
U_1	Primary vector
U_2	Secondary vector
A	Pairwise comparison matrix
λ_1	Primary eigenvalue
λ_2	Secondary eigenvalue
λ	Largest eigenvalue
$w_i(A)$	Weight of attributes
$\tilde{A}$	Neutrosophic pairwise
$\widetilde{m_{ij}}$	Elements of neutrosophic pairwise comparison matrix
$w_i(\tilde{A})$	Neutrosophic weight of attributes
$S\left(w_i(\tilde{A})\right)$	Crisp weight of attributes

If the pairwise comparison matrix is considered as $\tilde{A}=[\widetilde{m_{ij}}]_{n*n}, i, j= 1, \ldots ,n$ then weight of the attributes will be calculated exploiting the neutrosophic eigenvector-power technique algorithm as follows:

Step 1. Vector $U_0 = \begin{bmatrix} \langle(1,1,1,1);1,0,0\rangle \\ \vdots \\ \vdots \\ \langle(1,1,1,1);1,0,0\rangle \end{bmatrix}_{n*1}$ is assumed and the vector U_1 is calculated applying the equation $U_1 = (\tilde{A} \otimes U_0) \oslash \|\tilde{A} \otimes U_0\|_\infty$, where $\| W \|_\infty$ is infinity norm for every matrix like $W = \begin{bmatrix} a \\ b \\ c \\ \vdots \end{bmatrix}_{n*1}$ which is equal to its largest element.

Step 2. The value of λ_1 is calculated exploiting the equation $\lambda_1 = (U_1^T \otimes \tilde{A} \otimes U_1) \oslash (U_1^T \otimes U_1)$, where W^T is the Transpose for each vector like $W = \begin{bmatrix} a \\ b \\ c \\ \vdots \end{bmatrix}_{n*1}$ which is obtained using the equation $W^T = \begin{bmatrix} a & b & c & \cdots \end{bmatrix}_{1*n}$.

Step 3. The value of vector U_2 is calculated applying equation $U_2 = (\tilde{A} \otimes U_1) \oslash \|\tilde{A} \otimes U_1\|_\infty$.

Step 4. The value of λ_2 is calculated exploiting the equation $\lambda_2 = (U_2^T \otimes \tilde{A} \otimes U_2) \oslash (U_2^T \otimes U_2)$.

Step 5. If $|(\lambda_2 \ominus \lambda_1) \oslash \lambda_2| \leq \langle(\simeq 0, \simeq 0, < +\infty, < +\infty);[0,1],[0,1],[0,1]\rangle$, then value of λ_1 will be considered as an eigenvalue; Otherwise, the U_2 vector and the λ_2 value will be placed in the U_1 vector and in the λ_1 value, respectively and the third step will be repeated.

Step 6. N-equation set $\left(\tilde{A} \ominus \lambda_1 \otimes I\right) \otimes \begin{bmatrix} w_1(\tilde{A}) \\ \vdots \\ \vdots \\ w_n(\tilde{A}) \end{bmatrix}_{n*1} = \begin{bmatrix} \langle(0,0,0,0);1,0,0\rangle \\ \vdots \\ \vdots \\ \langle(0,0,0,0);1,0,0\rangle \end{bmatrix}_{n*1}$ is formed and then according to equation (3.8) is deneutrosophicated. The Identity matrix is assumed as follows:

$$I = \begin{bmatrix} \langle(1,1,1,1);1,0,0\rangle & \langle(0,0,0,0);1,0,0\rangle & \cdots & \langle(0,0,0,0);1,0,0\rangle \\ \langle(0,0,0,0);1,0,0\rangle & \langle(1,1,1,1);1,0,0\rangle & \cdots & \langle(0,0,0,0);1,0,0\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ \langle(0,0,0,0);1,0,0\rangle & \langle(0,0,0,0);1,0,0\rangle & \cdots & \langle(1,1,1,1);1,0,0\rangle \end{bmatrix}_{n*n}$$

Step 7. Crisp weight of the attributes is obtained exploiting the solution of previous step satisfy equation $\sum_i S\left(w_i(\tilde{A})\right) = 1$.

3.3 Performance gap analysis

Performance gap analysis is based on the weight of performance evaluation attributes which implies their significance. The analysis is performed by comparing the attributes' current performance with the desired one and the results were exploited to provide solutions with the aim of achieving the desired performance hence this was done according to the following two steps:

In the first step, paired comparison test was deployed in order to investigate existence of a significant difference between the current and the desired performance of evaluation attributes. In the second step, since significance of the attributes were not the same therefore, the weighted performance gap of the attributes was calculated via multiplying the weight of each attribute by its performance gap. Finally, weighted gap categorized as low, medium, high, and very high by using quartiles indicated that the greater it was the more critical it assumed.

4 Results

In the attribute weight questionnaire, 243 executives and employees were required to rate each attribute preference over the other attributes. Reliability of the questionnaire was confirmed by inconsistency ratio equal to 0.034. The pairwise comparison matrix which is geometric mean of all executives and employees' opinion aggregated according to Table 5.

Table 5: Pairwise comparison matrix

	$w_1(\tilde{A})$	$w_2(\tilde{A})$	$w_3(\tilde{A})$
$w_1(\tilde{A})$	$\langle(1,1,1,1);1,0,0\rangle$	$\langle(2.1,2.2,2.3,2.4);0.9,0.2,0.2\rangle$	$\langle(1.93,2.27,2.68,3.05);0.8,0.2,0.1\rangle$
$w_2(\tilde{A})$	$\langle(0.42,0.43,0.45,0.48);0.8,0.2,0.1\rangle$	$\langle(1,1,1,1);1,0,0\rangle$	$\langle(0.9,1,1.1,1.2);0.9,0.1,0.2\rangle$
$w_3(\tilde{A})$	$\langle(0.35,0.4,0.44,0.57);0.9,0.1,0.1\rangle$	$\langle(0.92,1,1.04,1.11);0.9,0.2,0.1\rangle$	$\langle(1,1,1,1);1,0,0\rangle$
$w_4(\tilde{A})$	$\langle(0.09,0.11,0.12,0.15);0.9,0.1,0.2\rangle$	$\langle(0.23,0.24,0.28,0.31);0.8,0.1,0.2\rangle$	$\langle(0.26,0.27,0.28,0.29);0.9,0.2,0.2\rangle$
$w_5(\tilde{A})$	$\langle(0.11,0.15,0.23,0.31);0.9,0.1,0.1\rangle$	$\langle(0.29,0.38,0.55,0.67);0.9,0.1,0.2\rangle$	$\langle(0.37,0.42,0.56,0.65);0.8,0.2,0.2\rangle$
$w_6(\tilde{A})$	$\langle(0.06,0.1,0.16,0.24);0.8,0.2,0.2\rangle$	$\langle(0.17,0.24,0.33,0.53);0.9,0.1,0.1\rangle$	$\langle(0.2,0.28,0.35,0.49);0.9,0.2,0.1\rangle$
$w_7(\tilde{A})$	$\langle(0.16,0.31,0.8,2.1);0.9,0.2,0.1\rangle$	$\langle(0.4,0.79,1.82,4.58);0.8,0.2,0.2\rangle$	$\langle(0.54,0.9,1.78,4.2);0.9,0.1,0.2\rangle$
$w_8(\tilde{A})$	$\langle(0.07,0.17,0.38,1.22);0.8,0.1,0.2\rangle$	$\langle(0.19,0.36,0.83,2.66);0.9,0.2,0.1\rangle$	$\langle(0.22,0.43,0.86,2.49);0.8,0.1,0.2\rangle$

Table 5. (continued)

	$w_4(\tilde{A})$	$w_5(\tilde{A})$	$w_6(\tilde{A})$
$w_1(\tilde{A})$	$\langle(6.81,8.32,10.02,11.95);0.9,0.1,0.2\rangle$	$\langle(3.24,4.28,6.69,8.86);0.9,0.2,0.1\rangle$	$\langle(4.25,6.3,9.57,16.19);0.8,0.1,0.2\rangle$
$w_2(\tilde{A})$	$\langle(3.21,3.89,4.44,4.56);0.9,0.2,0.2\rangle$	$\langle(1.5,1.82,2.66,3.48);0.8,0.2,0.2\rangle$	$\langle(1.89,3.06,4.15,5.84);0.9,0.2,0.1\rangle$
$w_3(\tilde{A})$	$\langle(3.5,3.6,3.7,3.8);0.8,0.2,0.1\rangle$	$\langle(1.54,1.8,2.4,2.69);0.9,0.1,0.2\rangle$	$\langle(2.04,2.83,3.53,4.96);0.9,0.2,0.2\rangle$
$w_4(\tilde{A})$	$\langle(1,1,1,1);1,0,0\rangle$	$\langle(0.4,0.5,0.6,0.7);0.9,0.2,0.1\rangle$	$\langle(0.57,0.74,0.94,1.23);0.8,0.2,0.1\rangle$
$w_5(\tilde{A})$	$\langle(1.43,1.67,2,2.5);0.9,0.2,0.1\rangle$	$\langle(1,1,1,1);1,0,0\rangle$	$\langle(1.3,1.4,1.5,1.6);0.9,0.1,0.2\rangle$
$w_6(\tilde{A})$	$\langle(0.81,1.07,1.36,1.75);0.8,0.1,0.2\rangle$	$\langle(0.63,0.67,0.71,0.77);0.9,0.2,0.2\rangle$	$\langle(1,1,1,1);1,0,0\rangle$
$w_7(\tilde{A})$	$\langle(2.12,3.36,6.61,16.8);0.9,0.2,0.2\rangle$	$\langle(1.53,2.2,3.5,7.12);0.8,0.1,0.2\rangle$	$\langle(2.5,3.33,5,10);0.9,0.1,0.1\rangle$
$w_8(\tilde{A})$	$\langle(0.88,1.66,3.51,8.65);0.9,0.1,0.1\rangle$	$\langle(0.69,1,1.79,3.88);0.8,0.2,0.1\rangle$	$\langle(1.17,1.63,2.58,5.39);0.9,0.2,0.1\rangle$

Table 5. (continued)

	$w_7(\tilde{A})$	$w_8(\tilde{A})$
$w_1(\tilde{A})$	$\langle(0.48,1.25,3.19,6.24);0.9,0.2,0.2\rangle$	$\langle(0.82,2.64,5.97,14.43);0.9,0.1,0.2\rangle$
$w_2(\tilde{A})$	$\langle(0.22,0.55,1.27,2.5);0.9,0.1,0.2\rangle$	$\langle(0.38,1.21,2.8,5.16);0.8,0.1,0.1\rangle$
$w_3(\tilde{A})$	$\langle(0.24,0.56,1.11,1.86);0.8,0.2,0.2\rangle$	$\langle(0.4,1.16,2.31,4.63);0.9,0.2,0.1\rangle$
$w_4(\tilde{A})$	$\langle(0.06,0.15,0.3,0.47);0.9,0.2,0.1\rangle$	$\langle(0.12,0.28,0.6,1.14);0.9,0.2,0.2\rangle$
$w_5(\tilde{A})$	$\langle(0.14,0.29,0.45,0.65);0.8,0.2,0.1\rangle$	$\langle(0.26,0.56,1,1.44);0.9,0.1,0.1\rangle$
$w_6(\tilde{A})$	$\langle(0.1,0.2,0.3,0.4);0.9,0.1,0.2\rangle$	$\langle(0.19,0.39,0.61,0.86);0.8,0.2,0.1\rangle$
$w_7(\tilde{A})$	$\langle(1,1,1,1);1,0,0\rangle$	$\langle(1.8,1.9,2,2.1);0.9,0.1,0.2\rangle$
$w_8(\tilde{A})$	$\langle(0.48,0.5,0.53,0.56);0.8,0.1,0.1\rangle$	$\langle(1,1,1,1);1,0,0\rangle$

The weight of attributes for health care services supply chain performance evaluation, including "treatment branding", "proportion of service with cost", "technological comfort", "treatment plan fulfilment", "access", "response to demands", "stakeholder's interests" and "job satisfaction of treatment staff" by applying the neutrosophic eigenvector-power technique deploying Excel were obtained respectively as $S\left(w_1(\tilde{A})\right) = 0.0411$,$S\left(w_2(\tilde{A})\right) = 0.0167$, $S\left(w_3(\tilde{A})\right) = 0.0149$,$S\left(w_4(\tilde{A})\right) = 0.0038$, $S\left(w_5(\tilde{A})\right) = 0.0061$, $S\left(w_6(\tilde{A})\right) = 0.2932$, $S\left(w_7(\tilde{A})\right) = 0.0082$ and $S\left(w_8(\tilde{A})\right) = 0.6160$.

In the gap analysis questionnaire, 236 patients were participated. Reliability of the questionnaire was confirmed by cronbach's alpha equal to 0.867. In order to investigate existence of a significant difference between the current and the desired performance of evaluation attributes, paired comparison test was used. Since distribution of the performance gaps was normal based on the Kolmogorov-Smirnov test, the paired t-test was exploited. The results showed that there were significant difference between the current and the desired performance of all evaluation attributes at the

0.05 significance level. Considering that significance of the attributes were not the same therefore, the weighted performance gap of the attributes was calculated via multiplying the weight of each attribute by its performance gap. The performance gap analysis results were shown in Table 6.

Table 6: erformance gap analysis

Attribute	Current Performance (Mean)	Desired Performance (Mean)	Performance Gap (Mean)	Attribute Weight	Weighted Performance Gap (Mean)	Weighted Performance Gap Span
treatment branding	2.9	5	2.1	0.0411	0.0863	high
proportion of service with cost	2.85	5	2.15	0.0167	0.0359	high
technological comfort	3.12	5	1.88	0.0149	0.0280	moderate
treatment plan fulfilment	3.20	5	1.80	0.0038	0.0068	low
access	3.29	5	1.71	0.0061	0.0104	low
response to demands	2.78	5	2.22	0.2932	0.6509	very high
stakeholder's interests	2.67	5	2.33	0.0082	0.0191	moderate
job satisfaction of treatment staff	3.04	5	1.96	0.6160	1.2074	very high

5 Discussion

By reviewing previous investigations it can be inferred that some researchers have only contented themselves with identifying and prioritizing healthcare supply chain performance attributes meanwhile, several inquirers have ranked healthcare supply chains in compliance with performance attributes. Göleç and Karadeniz [12] weighted attributes applying heuristic algorithm and compared performance of hospitals according to rule-based reasoning system [12]. Mohammadian et al. [19] weighted attributes deploying Analytical Hierarchy Process (AHP) technique and then performance of medical equipment supply chain management was accomplished according to attributes' performance percentage [19]. Moons et al. applied ANP technique to select operating room supply chains via performance indicators [20]. Leksono et al. [17] measured the performance of a sustainable healthcare supply chain through integration of a Balanced Scorecard, Decision Making Trial and Evaluation Laboratory (DEMATEL) and ANP techniques [17]. Tseng et al. [29] evaluated the performance of sustainable service supply chain management under uncertainty incorporated ANP and fuzzy logic [29]. Sari and Suslu [23] evaluated green performance of a hotel supply chain applying Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy logic [23]. Barari [7] ascertained weight of attributes and sub-attributes applying AHP technique to evaluate healthcare supply chain [7]. Ghahremanloo [11] evaluated hospitals performance based on Data Envelopment Analysis (DEA) and Best Worst Method (BWM) [11]. Supeekit et al. [26] evaluated internal hospital supply chain performance incorporating DEMATEL and ANP techniques [26]. These studies reveal that former performance evaluation models suffered the lack of exhaustive attributes which involve all aspects of healthcare supply chain. Besides, quantitative techniques used in these models have been in the fields of simulation, artificial intelligence, mathematical programming, and multiple attribute decision making each of which has some drawbacks. Multiple attribute decision making techniques have only prioritized attributes based on their weight or prioritized options based on their attributes. Comparing options with each other was done in these investigations but an evaluation model was not provided. In the system dynamics technique since there is not necessarily a scenario that optimizes all the performance attributes of the system, therefore it is not always possible to choose the best scenario. In the rule-based reasoning system, in addition to the fact that it is not possible to capture all required knowledge, the rules for inadequate data suffers lack of efficiency. The data envelopment analysis technique does not allow comparison of quality attributes of decision making units meanwhile, it is not possible to achieve optimal performance due to calculation of relative efficiency. In the interest of facing uncertainties in subjective judgments of experts, non-deterministic approaches have been used such as fuzzy logic, intuitionistic fuzzy logic, and grey numbers each of which has some flaws. Fuzzy logic lacks ability to face situations about which there is no knowledge, such that the decision maker encounters with a third state called uncertainty or doubt. Intuitionistic fuzzy logic is only appropriate for dealing with incomplete information, but it does not provide a solution to deal with uncertain and inconsistent information. Also, grey numbers are not able to explain degree of correctness or incorrectness.

This research used eigenvector-power technique for determine significance of performance evaluation attributes based on their pairwise comparisons in such a way that in addition to guaranteeing achievement of the largest eigenvalue, it resulted in reduction of required calculations. Weighted performance gap analysis of the attributes provided solutions and recommendations to achieve the attributes' desired performance. Given that conducting research requires collection and analysis of data available to experts therefore, adopting neutrosophic logic as a mechanism to face uncertainties in their subjective judgments brings more accurate evaluation and more reliable results.

6 Conclusion

In this research, healthcare services supply chain performance evaluation was conducted by applying objective attributes that focus on the outcome and subjective attributes that were based on judgment of evaluators. In this regard, neutrosophic logic has been deployed to face uncertainties in the expert's judgment while determining the priority of attributes over each other. Using power-eigenvector technique with the aim of ascertaining attributes importance, in addition to guarantee obtainment of the largest eigenvalue of the characteristic polynomial, has led to the reduction of calculations. Firstly, to go further it is recommended to formulating and analyzing influential relationships among these components via DEMATEL technique by developing mutual relationships and interdependencies in order to evaluate weaknesses and strengths of each component against another. Secondly, due to the fact that there is no substantial body of research on applied methodologies for building consensus in group management decision making, interactive management including Interpretive Structural Model (ISM) method could be applied to the system to better understand both direct and indirect relationships among the system's components in a hierarchical order. It provides logical links between elements to develop a visual map that is a higher level view of the system at hand which is deployed to obtain new insights, construct new approaches, form solutions and system level understanding of the structure.

References

[1] M. Abdel-Basset, G. Manogaran, A. Gamal, and F. Smarandache, *A hybrid approach of neutrosophic sets and DEMATEL method for developing supplier selection criteria*, Design Automat. Embed. Syst.**22** (2018), 257–278.

[2] L. Abdullah, Z. Ong, and S.M. Mahali, *Single-valued neutrosophic DEMATEL for segregating types of criteria: A case of subcontractors' selection*, J. Math. **4** (2021), 1–12.

[3] P. Adinolfi and E. Borgonovi, *The Myths of Healthcare Towards New Models of Leadership and Management in the Healthcare Sector*, Springer International Publishing, 2018.

[4] M. Al-Baali, L. Grandinetti, and A. Purnama, *Numerical analysis and optimization*, Springer International Publishing, 2017.

[5] E. Asgharizadeh, M. Taghaizadeh, and F. Andam, *Developing a model of healthcare services supply chain performance evaluation in Tehran's governmental, private and social security hospitals using grounded theory*, J. Health Promotion Manag. **13** (2023), no. 1, 1–20.

[6] S. Bag, L.C. Wood, L. Xu, P. Dhamija, and Y. Kayikci, *Big data analytics as an operational excellence approach to enhance sustainable supply chain performance*, Resources Conserv. Recycl. **153** (2020), 104559.

[7] A. Barari, *Healthcare supply chain evaluation using multi-criteria decision making*, Industrial Engineering Master of Science Thesis, University of Science and Culture, 2018.

[8] B.P. Bergeron, *Performance Management in Healthcare From Key Performance Indicators to Balanced Scorecard*, CRC Press, 2017.

[9] S. Bordoloi, J. Fitzsimmons, and M. Fitzsimmons, *Service Management: Operations, Strategy, Information Technology*, McGraw-Hill Education, 2022.

[10] V. Duque-Uribe, W. Sarache, and E.V. Gutiérrez, *Sustainable supply chain management practices and sustainable performance in hospitals: A systematic review and integrative framework*, Sustainability **11** (2019), no. 21, 5949.

[11] M. Ghahremanloo, *A hybrid performance assessment model based on the data envelopment analysis and multi-criteria decision making (Case study: Hospitals)*, Industrial Management Master of Science Thesis, Shahrood University of Technology, 2018.

[12] A. Göleç and G. Karadeniz, *Performance analysis of healthcare supply chain management with competency-based operation evaluation*, Comput. Ind. Engin. **146** (2020), 106546.

[13] D. Ivanov and A. Dolgui, *A digital supply chain twin for managing the disruption risks and resilience in the era of industry 4.0*, Prod. Plann. Control **32** (2021), no. 9, 775–788.

[14] C. Kahraman and I. Otay, *Fuzzy multi-criteria decision-making using neutrosophic sets*, Springer, 2019.

[15] S.S. Kamble, A. Gunasekaran, A. Ghadge, and R. Raut, *A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs-a review and empirical investigation*, Int. J. Prod. Econ. **229** (2020), 107853.

[16] J.R. Langabeer, *Performance Improvement in Hospitals and Health Systems Managing Analytics and Quality in Healthcare*, CRC Press, 2018.

[17] E.B. Leksono, S. Suparno, and I. Vanany, *Integration of a balanced scorecard, DEMATEL, and ANP for measuring the performance of a sustainable healthcare supply chain*, Sustainability **11** (2019), no. 13, 3626.

[18] C.R. McConnell, *Hospitals and Health Systems What They are and How They Work*, Jones & Bartlett Learning, 2020.

[19] M. Mohammadian, M. Yaghoubi, M.A. Jarrahi, M. Babaei, M. Bahadori, and E. Teymourzadeh, *Evaluating the performance of medical equipment supply chain management in military hospitals: A case study*, J. Military Med. **23** (2021), no. 1, 75–89.

[20] K. Moons, G. Waeyenbergh, L. Pintelon, P. Timmermans, and D. De Ridder, *Performance indicator selection for operating room supply chains: An application of ANP*, Oper. Res. Health Care **23** (2019), 100229.

[21] M.A. Pfannstiel and C. Rasche, *Service Business Model Innovation in Healthcare and Hospital Management Models, Strategies, Tools*, Springer International Publishing, 2017.

[22] M.A. Pfannstiel and C. Rasche, *Service Design and Service Thinking in Healthcare and Hospital Management Theory, Concepts, Practice*, Springer International Publishing, 2019.

[23] K. Sari and M. Suslu, *A modeling approach for evaluating green performance of a hotel supply chain*, Technol. Forecast. Soc. Change **137** (2018), 1–8.

[24] H. Singh, *Essentials of Management for Healthcare Professionals*, CRC Press, 2021.

[25] G.L. Stewart and G.B. Kenneth, *Human Resource Management: Linking Strategy to Practice*, Wiley, 2010.

[26] T. Supeekit, T. Somboonwiwat, and D. Kritchanchai, *DEMATEL-modified ANP to evaluate internal hospital supply chain performance*, Comput. Ind. Engin.**102** (2016), 318–330.

[27] K. Tas, A. Tas, and F.B. Isin, *I-Valued neutrosophic AHP: an application to assess airline service quality after covid-19 pandemy*, Neutrosophic Sets Syst. **49** (2022), no. 1, 424-437.

[28] N.W. Tierney, *Value Management in Healthcare How to Establish a Value Management Office to Support Value-Based Outcomes in Healthcare*, CRC Press, 2018.

[29] M.L. Tseng, M.K. Lim, W.P. Wong, Y.C. Chen, and Y. Zhan, *A framework for evaluating the performance of sustainable service supply chain management under uncertainty*, Int. J. Prod. Econ. **195** (2018), 359–372.

[30] P. Turner, *Leadership in Healthcare Delivering Organisational Transformation and Operational Excellence*, Palgrave Macmillan, 2019.

[31] G. Tzeng and J. Huang, *Multiple Attribute Decision Making Methods and Applications*, CRC Press, 2011.

[32] A. Vafadarnikjoo, M. Tavana, T. Botelho, and K. Chalvatzis, *A neutrosophic enhanced best-worst method for considering decision-makers' confidence in the best and worst criteria*, Ann. Oper. Res. **289** (2020), no. 2, 391–418.

[33] X. Wu and H. Liao, *Geometric linguistic scale and its application in multi-attribute decision-making for green agricultural product supplier selection*, Fuzzy Sets Syst. **458** (2023), 182–200.

[34] R.M. Zulqarnain, X.L. Xin, M. Saqlain, F. Smarandache, and M.I. Ahamad, *An integrated model of neutrosophic TOPSIS with application in multi-criteria decision-making problem*, Neutrosophic Sets Syst. **40** (2021), 117–133.