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Research Article

Health Insurance Provider Selection Through Novel Correlation Measure of Neutrosophic Sets Using TOPSIS

B.S. Mahapatra[1], M.B. Bera[1], M.K. Mondal[1], Florentin Smarandache[2*], G.S. Mahapatra[3]

[1] School of Applied Science and Humanities, Haldia Institute of Technology, Haldia-721657, India
[2] Department of Mathematics, University of New Mexico, 705 Gurley Ave., Gallup, NM 87301, United States
[3] Department of Mathematics, National Institute of Technology Puducherry, Karaikal 609609, India
E-mail: smarand@unm.edu

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Abstract: Risk monitoring aims to recognize and control potential threats to our assets or health activities. Insurance is vital, as it compensates for any unexpected loss of property or life. Clients selecting the best health insurance provider must consider various factors and their relative significance to their circumstances. Multi-criteria decision-making (MCDM) helps people analyze and compare policy alternatives to find the best option. This research aims to assist potential health policy purchasers by addressing the selection of health insurance providers as an MCDM problem. The correlation coefficient is useful for identifying the importance of several conflicting criteria. The idea of correlation coefficients is extended in a neutrosophic context to capture the indeterminacy and incomplete information in the relationship among the criteria. The technique for order preference by similarity to an ideal solution (TOPSIS) approach is a useful and straightforward approach to solving MCDM problems. However, it often became ambiguous to researchers due to its involvement in the distance measure technique. The proposed neutrosophic correlation measure may also replace the ambiguity of using a suitable distance measure in the TOPSIS approach. This study extends the TOPSIS method by using the proposed neutrosophic correlation coefficient on single-valued neutrosophic sets (SVNSs). The criteria preferences are computed using a method based on the removal effects of the criteria (MEREC) approach. Some valuable concepts, like the weighted closeness measure of type I and type II and the weighted index parameter, are introduced with their properties to establish the proposed neutrosophic TOPSIS approach. An MCDM approach for health insurance providers has been constructed to illustrate the proposed approach numerically. The proposed method suggest that the health insurance provider Υ_2 is the most beneficial alternative, whereas Υ_1 is the least suitable. The client considers the terms and conditions for non-coverage and the facilities provided for pediatric and maternity care while buying health insurance. The comparative analysis of the suggested technique demonstrates the merit of the research in terms of consistency. The sensitivity analysis demonstrates the flexibility and robustness of the obtained results.

Keywords: correlation measure, TOPSIS, single-valued neutrosophic set, MCDM, health insurance, MEREC

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1. Introduction

Risk management is the rational creation and implementation of a loss mitigation strategy [1]. Risk monitoring entails detecting possible risks in advance, analyzing them, and taking preventative measures to mitigate them [2]. Insurance is an essential component of risk management in modern society, and its primary objective is to protect human life. An individual can take life insurance in two ways: health insurance for medical care and endowment insurance with a built-in savings component. Health insurance covers the costs associated with medical treatment for policyholders who sustain injuries or illnesses due to a catastrophe within the policy period [3]. Health insurance is popular because it offers financial protection, access to quality healthcare, preventive care services, peace of mind, and tax benefits.

After the globalization of India in the early 1990s, private players became interested in investing in the health sector. As a result, the rapid growth of private health insurance providers (HIPs) is entering the market, offering various health insurance products [4]. The Indian government launched Ayushman Bharat in 2018 to provide health coverage to over 100 million vulnerable families [5]. People who do not belong to the vulnerable class have discovered that they need to insure themselves to obtain better medical treatment than government hospitals. Many people need help choosing HIPs due to the lack of information regarding the plans and the fact that, even if such information were available, it would only describe the HIPs' features using linguistic terms that they struggle to categorize. In this process, ambiguity and incompleteness are introduced into the decision-making procedure. Therefore, it is highly challenging for a decision-maker (DM) to evaluate the characteristics of the HIPs and rank them in order of importance. This article formulates the issue of picking the best HIP as a multi-criteria decision-making (MCDM) problem, aiming to assist the health insurance buyer.

The MCDM offers a systematic technique for decision-making involving multiple conflicting criteria, which assists DMs by considering a broader overview of factors and their interrelationships [6]. The TOPSIS approach, introduced by Hwang and Yoon [7] and improved by Hwang et al. [8], is a popular MCDM technique for sound logic, greater flexibility, a more straightforward calculation procedure, and a distance measure simultaneously for the most preferable and least desirable outcomes [9]. The description of the criteria often needs to be completed or is indeterminate in the MCDM process, and the quantitative assessment of these criteria often depends on the subjective judgments of the DMs. Hence, it is only possible to accurately assess this complete information through the subjective assessment of the DMs. TOPSIS offers a methodical and adaptable MCDM framework, effectively managing uncertainty by incorporating subjective assessments and facilitating a transparent decision-making procedure. TOPSIS ranks the alternatives by identifying the ideal solutions through distance measurement. In an uncertain context, there needs to be a definitive guideline regarding the optimal distance measurement among various alternatives (e.g., Euclidean, Hamming, and Taxicab), which brings ambiguity into the decision-making procedure.

Data and information on the criteria of an option are frequently combined with hesitancy, indeterminacy, and uncertainty in the MCDM problem. In particular, MCDM techniques are vulnerable to the subjectivity of the experts when they use linguistic ideas for assessment. The idea of fuzzy sets (FSs) [10] with a membership degree offers a better option to handle these uncertain MCDM problems. The intuitionistic fuzzy set (IFS) [11], Pythagorean fuzzy set [12], and fermatean fuzzy set [13] are extensions of FS with two membership functions describing the acceptance and rejection degree with certain conditions. These FSs can handle ambiguous and partial data, not indeterminate or inconsistent information [14]. Smarandache [15] introduced the neutrosophic set (NS) with the neutrosophy ideology [16] that every idea has some degree of falsehood and indeterminacy in addition to truth. The single-valued neutrosophic sets (SVNSs) [17] are generalizations of FSs, IFSs, PFSs, and FFSs. It has three independent membership functions, all of which lie in [0, 1] and reflect truth, indeterminacy, and falsity. As a result, SVNS is a better choice for representing the linguistic evaluation of the criteria in MCDM.

The purpose and aim of this article are as follows:

• The HIP selection problem can be formulated as a decision-making problem analyzing the key features of the different HIPs.

• The TOPSIS method can incorporate a neutrosophic correlation to eliminate the uncertainty of selecting distance measures in an ambiguous context.

• A criteria weight determination procedure may be used to evaluate the objective relevance of a criterion, eliminating the expert's subjective judgment of the criteria.

• An integrated TOPSIS approach can be introduced to deal with uncertain MCDM issues for a more accurate and reliable evaluation of decision-making.

To track the remaining article, Section 2 writes up the related literature that highlights the study's reason and research gap. In Section 3, the fundamental idea of the neutrosophic set is discussed. The concept of the neutrosophic correlation coefficient is proposed in Section 4. An integrated neutrosophic correlation-based TOPSIS approach is suggested in Section 5. The numerical illustration of HIP selection, comparison, and sensitivity analysis is presented in Section 6. The findings of this study are discussed in Section 7 along with a few potential suggestions for future work.

2. Literature review

This part provides a related study on MCDM application in the healthcare industry and the development of neutrosophic MCDM approaches.

2.1 *Selection of health insurance using MCDM*

The MCDM model can be a valuable process for selecting any service provider for performance analysis. Some researchers tried to apply crisp and fuzzy decision-making approaches to assess the performance of insurance companies. Gharizadeh et al. [18] introduced an integrated approach for performance analysis of insurance companies through AHP and principal component analysis. Susanto and Utama [19] considered fuzzy and non-fuzzy parameters in the claim settlement of the insurance companies, where the AHP approach determines the criteria preferences. Zulkifly et al. [20] proposed a fuzzy TOPSIS approach to find the rank of HIPs. A combined fuzzy AHP and fuzzy TOPSIS approach was proposed by Kahraman et al. [21] to assist potential buyers of health insurance. Erdebilli et al. [22] applied q-rof fuzzy set-based TOPSIS and VIKOR approaches to assess private health insurance plans. Yang et al. [23] introduced an algorithm that depends on q-rof sets, interactive, and Maclaurin symmetric mean operators for the financial performance of insurance companies. Mishra et al. [24] proposed a divergence measure and extended the TODIM [Portuguese acronym for Interactive Multi-Criteria Decision Making] approach using the proposed measure for vehicle insurance quality assessment. A group decision-making (GDM) framework was formulated by Yucenur and Demirel [25] using the extended VIKOR approach to determine the suitable HIPs for forest investment. An intuitionistic fuzzy method based on the removal effects of criteria (MEREC)-MARCOS approach was developed for GDM to assess the operational effectiveness of the insurance companies [26].

2.2 *Neutrosophic TOPSIS approach*

The neutrosophic fuzzy set [15], which Smarandache proposed as a generalization of the IFS, is capable of handling inaccurate information (uncertain, inaccurate, incomplete, and vague information) and is based on truth, indeterminacy, and falsity. Several distance measures, operators, and correlation measures were implemented on SVNS to solve the MCDM problem. Among them, Luo et al. [27] established a distance measure on SVNS for pattern recognition. Zhang et al. [28] proposed a neutrosophic TODIM-BSC method to assess the efficiency of insurance firms. Singh et al. [29] suggested an inter-valued neutrosophic fuzzy approach through principal component analysis.

There are several articles [30] that include in-depth simulation-based comparisons and mathematical analysis of TOPSIS to clear the ambiguity over which one should be used to solve MCDM problems. TOPSIS is a popular and effective way to handle MCDM issues in an uncertain environment. The conventional TOPSIS method considers only distance measures, not similarity or probability. Biswas et al. [31] solved TOPSIS by SVN Euclidean distance measure. Karasan and Kaya [32] proposed a neutrosophic TOPSIS approach for evaluating different network controllers and relays for aerial vehicles. Hezam et al. [33] applied neutrosophic TOPSIS to rank COVID-19 vaccine alternatives. Pouresmaeil et al. [34] constructed a score function to solve interval neutrosophic MCDM problems using the TOPSIS approach.

Mollaoglu et al. [35] identified alternate fuel sources for ship investment choices using the neutrosophic TOPSIS approach. Some recent applications of the neutrosophic TOPSIS approach are summarised in Table 1.

Table 1. Recent applications of neutrosophic TOPSIS approach

Approach	Weight determination	Applications	Reference
Neutrosophic TOPSIS	ANP	Tourist destination selection	[36]
Neutrosophic TOPSIS and COPRAS	AHP	Women university selection	[37]
Neutrosophic TOPSIS	Average method	Surfactant-free microemulsion fuel selection	[38]
Single-valued neutrosophic TOPSIS	Term presence and term frequency	Doctor selection	[39]
Neutrosophic TOPSIS	CRITIC	Aircraft selection	[40]
Neutrosophic TOPSIS	CRITIC and entropy	Best player selection	[41]
Triangular neutrosophic TOPSIS	Average method	Renewable energy source selection	[42]
Single-valued neutrosophic TOPSIS	Neutrosophic rating	Cloud service selection	[43]
Neutrosophic TOPSIS	Neutrosophic rating	Nutritional education strategies selection	[44]
Neutrosophic TOPSIS	AHP	Ideal manufacture selection	[45]
Neutrosophic TOPSIS		Smartphone selection	[46]
Single-valued neutrosophic TOPSIS		Software development company selection	[47]
Neutrosophic TOPSIS	Single-valued neutrosophic weighted averaging operator	Logistic selection	[48]
Neutrosophic AHP and TOPSIS	AHP	Smart village selection	[49]
Single-valued neutrosophic TOPSIS	Single-valued neutrosophic weighted averaging operator	Tablet selection	[50]
Single-valued neutrosophic TOPSIS	Subject	e-commerce development strategies	[51]
Single-valued neutrosophic TOPSIS	Single-valued neutrosophic weighted averaging operator	Software project selection	[52]
		Logistic centre location selection	[53]

Implementing various neutrosophic TOPSIS approaches in the MCDM and multi-criteria GDM problems is convenient, as seen in Table 1. However, there are few papers on insurance policy selection treated as an MCDM problem and solved by fuzzy TOPSIS: Sehhat et al. [54] used a crisp TOPSIS approach; Mimovic et al. [55] used interval fuzzy rough sets-based TOPSIS; Sekar et al. [56] and Chu and Le [57] used fuzzy TOPSIS. Neutrosophic TOPSIS has a wide range of applications, although HIP selection is not mentioned as an MCDM problem in any of the current literature, according to Table 1.

The evaluation of the significance of the criterion is of utmost relevance in MCDM procedures. The criteria weights may be decided by subjective evaluation by an expert or objective assessment using the decision matrix. The subjective evaluation often entails individual preferences and the expert's inability to judge accurately. To eliminate this issue, using an objective evaluation method using statistical or mathematical techniques is preferable. The MEREC technique has several benefits, such as identifying duplicate criteria, simplicity and intuitiveness, flexibility in adjusting decisions, resilience to uncertainty, transparency and involvement of stakeholders, and compatibility with other methods. The collective advantages of these aspects make the MEREC technique more effective and appropriate for determining criterion preference.

2.3 *Fuzzy correlation-based TOPSIS approach*

In practice, correlation coefficients are often employed to assess relationships between variables and are utilized in various disciplines. Karl Pearson first introduced the correlation coefficient to deal with crisp numbers. Chiang and Lin [58] introduced the fuzzy correlation coefficient to show whether the fuzzy sets are positively or negatively correlated. Ye [59] proposed intuitionistic decision-making based on weighted correlation coefficients. Lin et al. [60] developed a Pythagorean correlation coefficient-based TOPSIS approach for inpatient stroke rehabilitation analysis. Golui et al. [61] suggested a correlation for the fermatean fuzzy-based TOPSIS approach considering the hesitant components and applied it for ranking electric vehicles. Zhang et al. [62] introduced a hesitant fuzzy-based correlation for supplier selection. Liu et al. [63] proposed a hesitant fuzzy correlation coefficient for medical diagnosis challenges. Ye [64, 65] proposed the SVNS correlation coefficient and extended this idea to cosine similarity measures to solve MCDM problems. Zeng et al. [66] proposed a correlation between SVNSs and applied TOPSIS for software selection.

Except for Zeng et al. [66], all correlation coefficients reported in previous studies fall within the [0, 1] range. Consequently, we need to represent the negative correlation between SVNSs accurately. This work suggests a novel idea for the SVNS correlation coefficient to address the drawbacks of the current correlation coefficients. The main advantage of this approach is that the proposed SVNS correlation coefficient lies in $[-1, 1]$, which is identical to the traditional statistical measure.

According to the research gap, the following are the article's contributions:

• A more robust correlation coefficient was devised to quantify the strength of the associations between SVNSs, encompassing both positive and negative relationships.

• A correlation-based integrated TOPSIS method is proposed for addressing uncertain MCDM problems.

• The MEREC approach's weight determination replaces the TOPSIS approach's subjective weight assessment of the criteria.

• A healthcare provider analysis is developed as an MCDM problem by identifying viable alternatives and their associated criteria.

• The proposed approach is compared with distance-based TOPSIS approaches to check its consistency.

• Sensitivity analysis generates a collection of uncertain decision-making by varying the parameters.

3. Preliminaries

This section provides the basic arithmetic operations on SVNSs.

Definition 1 Single-valued neutrosophic set (SVNS): [17] Suppose $\xi_{\tilde{P}}$, $\zeta_{\tilde{P}}$, $\kappa_{\tilde{P}}$: $\mathbf{R} \to [0, 1]$ denote the truth, hesitation, and falsity membership functions, respectively, then an SVNS $\tilde{P}$ of a single-valued independent variable t is defined by $\tilde{P} = \{\langle t; [\, \xi_{\tilde{P}}(t), \zeta_{\tilde{P}}(t), \kappa_{\tilde{P}}(t)] \,\rangle : t \in T\}$, where T is the universal set.

A diagram of the SVNS is given in Figure 1.

For simplicity, we use $\tilde{p} = (\xi_p, \zeta_p, \kappa_p)$ as single-valued neutrosophic element (SVNE) instead of SVNS.

Definition 2 Arithmetic operations of SVNEs: [67] Suppose $\tilde{p} = (\xi_p, \zeta_p, \kappa_p)$ and $\tilde{q} = (\xi_q, \zeta_q, \kappa_q)$ be any two SVNEs and $\lambda \neq 0$ be real constant. The algebraic operations are described as follows:

$$\tilde{p} \bigoplus \tilde{q} = (\xi_p + \xi_q - \xi_p\xi_q, \zeta_p\zeta_q, \kappa_p\kappa_q)$$

$$\tilde{p} \bigotimes \tilde{q} = (\xi_p\xi_q, \zeta_p + \zeta_q - \zeta_p\zeta_q, \kappa_p + \kappa_q - \kappa_p\kappa_q)$$

$$\lambda \tilde{p} = (1 - (1 - \xi_p)^{\lambda}, \zeta_p^{\lambda}, \kappa_p^{\lambda})$$

$$\tilde{p}^{\lambda} = (\xi_p^{\lambda}, 1-(1-\zeta_p)^{\lambda}, 1-(1-\kappa_p)^{\lambda})$$

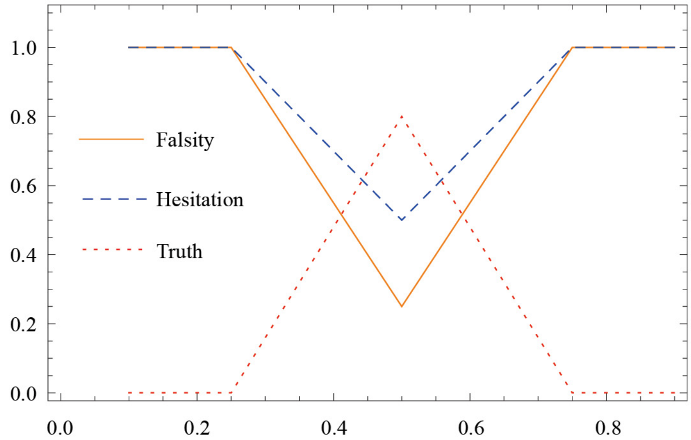

Figure 1. Diagram of a single-valued neutrosophic sets

Definition 3 Score function: [68] The score function of a SVNE $\tilde{p} = (\xi_p, \zeta_p, \kappa_p)$ is described by:

$$\mathfrak{S}_p = \frac{3+\xi_p - 2\zeta_p - \kappa_p}{4}; \mathfrak{S} \in [0, 1] \tag{1}$$

4. Proposed single-valued neutrosophic correlation coefficient

This part proposes a neutrosophic correlation coefficient and its distinctive characteristics. The weighted neutrosophic correlation coefficient is also introduced and established by describing its properties.

Let us consider m distinct alternatives defined as $\Upsilon = \{\Upsilon_1, \Upsilon_2, ..., \Upsilon_m\}$ and n criteria $\Psi = \{\Psi_1, \Psi_2, ..., \Psi_n\}$, where Ψ_B and Ψ_C respectively, be the collection of benefit-based and cost-based criteria, such that $\Psi = \Psi_B \cup \Psi_C$ and $\Psi_B \cap \Psi_C = \emptyset$. Let $\varsigma = (\varsigma_1, \varsigma_2, ..., \varsigma_n)$ be the criteria weights such that $\sum_{i=1}^{n} \varsigma_j = 1$. Each entry in the decision matrix $\mathbb{M} = (m_{ij})_{m\times n}$ is SVNS, as shown below:

$$\mathbb{M} = \begin{array}{c} \\ \Upsilon_1 \\ \Upsilon_2 \\ \vdots \\ \Upsilon_m \end{array} \begin{array}{c} \begin{array}{ccccc} \Psi_1 & \Psi_2 & \Psi_3 & \cdots & \Psi_n \end{array} \\ \begin{pmatrix} (\xi_{11}, \zeta_{11}, \kappa_{11}) & (\xi_{12}, \zeta_{12}, \kappa_{12}) & (\xi_{13}, \zeta_{13}, \kappa_{13}) & \cdots & (\xi_{1n}, \zeta_{1n}, \kappa_{1n}) \\ (\xi_{21}, \zeta_{21}, \kappa_{21}) & (\xi_{22}, \zeta_{22}, \kappa_{22}) & (\xi_{23}, \zeta_{23}, \kappa_{23}) & \cdots & (\xi_{2n}, \zeta_{2n}, \kappa_{2n}) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ (\xi_{m1}, \zeta_{m1}, \kappa_{m1}) & (\xi_{m2}, \zeta_{m2}, \kappa_{m2}) & (\xi_{m3}, \zeta_{m3}, \kappa_{m3}) & \cdots & (\xi_{mn}, \zeta_{mn}, \kappa_{mn}) \end{pmatrix} \end{array} \tag{2}$$

The element $m_{ij} = (\xi_{ij},\ \zeta_{ij},\ \kappa_{ij})$ denotes the ij^{th} rating of SVNS in the decision matrix (2) by the expert. The characteristic m_i corresponding to the alternative Υ_i in the i^{th} row is represented as

$$m_i = \{(c_1,\ \xi_{i1},\ \zeta_{i1},\ \kappa_{i1}),\ (c_2,\ \xi_{i2},\ \zeta_{i2},\ \kappa_{i2}),\ ...,\ (c_n,\ \xi_{in},\ \zeta_{in},\ \kappa_{in})\}.$$

Definition 4 Neutrosophic correlation coefficient: Let Υ_s and Υ_t represent two neutrosophic characteristics of an alternative in the neutrosophic decision matrix $\mathbb{M}$ respectively, where

$$\Upsilon_s = \{(c_1,\ \xi_{s1},\ \zeta_{s1},\ \kappa_{s1}),\ (c_2,\ \xi_{s2},\ \zeta_{s2},\ \kappa_{s2}),\ ...,\ (c_n,\ \xi_{sn},\ \zeta_{sn},\ \kappa_{sn})\}$$

$$\Upsilon_t = \{(c_1,\ \xi_{t1},\ \zeta_{t1},\ \kappa_{e1}),\ (c_2,\ \xi_{t2},\ \zeta_{t2},\ \kappa_{t2}),\ ...,\ (c_n,\ \xi_{tn},\ \zeta_{tn},\ \kappa_{tn})\}$$

Suppose $\bar{\xi_j} = \sum_{i=1}^{m} \xi_{ij}/m,\ \bar{\zeta_j} = \sum_{i=1}^{m} \zeta_{ij}/m,$ and $\bar{\kappa_j} = \sum_{i=1}^{m} \kappa_{ij}/m,$ then the neutrosophic correlation coefficient between Υ_s and Υ_t is defined as follows:

$$\vartheta(\Upsilon_s,\ \Upsilon_t) = \frac{1}{3}\left[\rho_\xi(\Upsilon_s,\ \Upsilon_t) + \rho_\zeta(\Upsilon_s,\ \Upsilon_t) + \rho_\kappa(\Upsilon_s,\ \Upsilon_t)\right] \tag{3}$$

where

$$\rho_\xi(\Upsilon_s,\ \Upsilon_t) = \frac{\sum_{j=1}^{n}\left[\xi_{sj}^2 - \bar{\xi}_j^2\right]\left[\xi_{tj}^2 - \bar{\xi}_j^2\right]}{\sqrt{\sum_{j=1}^{n}\left[\xi_{sj}^2 - \bar{\xi}_j^2\right]^2}\sqrt{\sum_{j=1}^{n}\left[\xi_{tj}^2 - \bar{\xi}_j^2\right]^2}},$$

$$\rho_\zeta(\Upsilon_s,\ \Upsilon_t) = \frac{\sum_{j=1}^{n}\left[\zeta_{sj}^2 - \bar{\zeta}_j^2\right]\left[\zeta_{tj}^2 - \bar{\zeta}_j^2\right]}{\sqrt{\sum_{j=1}^{n}\left[\zeta_{sj}^2 - \bar{\zeta}_j^2\right]^2}\sqrt{\sum_{j=1}^{n}\left[\zeta_{tj}^2 - \bar{\zeta}_j^2\right]^2}},$$

and

$$\rho_\kappa(\Upsilon_s,\ \Upsilon_t) = \frac{\sum_{j=1}^{n}\left[\kappa_{sj}^2 - \bar{\kappa}_j^2\right]\left[\kappa_{tj}^2 - \bar{\kappa}_j^2\right]}{\sqrt{\sum_{j=1}^{n}\left[\kappa_{sj}^2 - \bar{\kappa}_j^2\right]^2}\sqrt{\sum_{j=1}^{n}\left[\kappa_{tj}^2 - \bar{\kappa}_j^2\right]^2}}.$$

We assume that the denominators of $\rho_\xi(\Upsilon_s,\ \Upsilon_t),\ \rho_\zeta(\Upsilon_s,\ \Upsilon_t),\ \rho_\kappa(\Upsilon_s,\ \Upsilon_t)$ are not equal to zero.

Definition 5 Weighted neutrosophic correlation coefficient: Let $\Upsilon_s,\ \Upsilon_t$ be the two neutrosophic characteristics in the neutrosophic decision matrix $\mathbb{M}$ and $\varsigma = (\varsigma_1,\ \varsigma_2,\ ...,\ \varsigma_n),\ \sum_{j=1}^{n} \varsigma_j = 1$ be the weight vector related to the criteria. Then, the weighted neutrosophic correlation coefficient between $\Upsilon_s,\ \Upsilon_t$ is defined as follows:

$$\vartheta^{\varsigma}(\Upsilon_s, \Upsilon_t) = \frac{1}{3}\left[\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t) + \rho_{\zeta}^{\varsigma}(\Upsilon_s, \Upsilon_t) + \rho_{\kappa}^{\varsigma}(\Upsilon_s, \Upsilon_t)\right] \tag{4}$$

where,

$$\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t) = \frac{\sum_{j=1}^{n} \varsigma_j \left[\xi_{sj}^2 - \bar{\xi_j^2}\right] \cdot \left[\xi_{tj}^2 - \bar{\xi_j^2}\right]}{\sqrt{\sum_{j=1}^{n} \varsigma_j \left[\xi_{sj}^2 - \bar{\xi_j^2}\right]^2} \cdot \sqrt{\sum_{j=1}^{n} \varsigma_j \left[\xi_{tj}^2 - \bar{\xi_j^2}\right]^2}} \tag{5}$$

$$\rho_{\zeta}^{\varsigma}(\Upsilon_s, \Upsilon_t) = \frac{\sum_{j=1}^{n} \varsigma_j \left[\zeta_{sj}^2 - \bar{\zeta_j^2}\right] \cdot \left[\zeta_{tj}^2 - \bar{\zeta_j^2}\right]}{\sqrt{\sum_{j=1}^{n} \varsigma_j \left[\zeta_{sj}^2 - \bar{\zeta_j^2}\right]^2} \cdot \sqrt{\sum_{j=1}^{n} \varsigma_j \left[\zeta_{tj}^2 - \bar{\zeta_j^2}\right]^2}} \tag{6}$$

$$\rho_{\kappa}^{\varsigma}(\Upsilon_s, \Upsilon_t) = \frac{\sum_{j=1}^{n} \varsigma_j \left[\kappa_{sj}^2 - \bar{\kappa_j^2}\right] \cdot \left[\kappa_{tj}^2 - \bar{\kappa_j^2}\right]}{\sqrt{\sum_{j=1}^{n} \varsigma_j \left[\kappa_{sj}^2 - \bar{\kappa_j^2}\right]^2} \cdot \sqrt{\sum_{j=1}^{n} \varsigma_j \left[\kappa_{tj}^2 - \bar{\kappa_j^2}\right]^2}}. \tag{7}$$

The denominators of the equations (5), (6), and (7) are assumed to be non-zero.

Theorem 1 The membership component $\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t)$ of $\vartheta^{\varsigma}(\Upsilon_s, \Upsilon_t)$ satisfy the following characteristics:

(i) $\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t) = \rho_{\xi}^{\varsigma}(\Upsilon_t, \Upsilon_s)$

(ii) $\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t) = 1$ if $\xi_{sj} = \xi_{tj}\ \forall\, c_j \in \Psi$

(iii) $|\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t)| \leq 1$

Proof. The properties (i) and (ii) are trivial as $\rho_{\xi}^{\varsigma}(\Upsilon_s, \Upsilon_t) = \frac{\sum_{j=1}^{n} \varsigma_j \left[\xi_{sj}^2 - \bar{\xi_j^2}\right]^2}{\left[\sqrt{\sum_{j=1}^{n} \varsigma_j \left[\xi_{sj}^2 - \bar{\xi_j^2}\right]^2}\right]^2} = 1$. To prove (iii), it is known that $-1 \leq \left((\xi_{sj})^2 - (\bar{\xi_j})^2\right) \cdot \left((\xi_{tj})^2 - (\bar{\xi_j})^2\right) \leq 1$. Thus, $-1 \leq \sum_{j=1}^{n} \varsigma_j \left((\xi_{sj})^2 - (\bar{\xi_j})^2\right) \cdot \left((\xi_{tj})^2 - (\bar{\xi_j})^2\right) \leq 1$, since $\sum_{j=1}^{n} \varsigma_j = 1$.

The denominator of (5) is $0 \leq \sum_{j=1}^{n} \left((\xi_{sj})^2 - (\bar{\xi_j})^2\right)^2 \leq n$ and $0 \leq \sum_{j=1}^{n} \left((\xi_{tj})^2 - (\bar{\xi_j})^2\right)^2 \leq n$.

So it is obvious that $0 \leq \sum_{j=1}^{n} \varsigma_j \left((\xi_{sj})^2 - (\bar{\xi_j})^2\right)^2 \leq 1$ and $0 \leq \sum_{j=1}^{n} \varsigma_j \left((\xi_{tj})^2 - (\bar{\xi_j})^2\right)^2 \leq 1$ since $\sum_{j=1}^{n} \varsigma_j = 1$.

Hence, $\sqrt{\sum_{j=1}^{n} \varsigma_j \left((\xi_{sj})^2 - (\bar{\xi_j})^2\right)^2} \cdot \sqrt{\sum_{j=1}^{n} \varsigma_j \left((\xi_{tj})^2 - (\bar{\xi_j})^2\right)^2} \leq \sqrt{1}.\sqrt{1} = 1$.

Similarly, it can be shown $-1 \leq \rho_{\xi}(\Upsilon_s, \Upsilon_t) \leq 1$, this establishes the theorem.

5. Proposed integrated neutrosophic TOPSIS approach

The current section illustrates the suggested neutrosophic TOPSIS methodology to solve uncertain MCDM issues.

Definition 6 Neutrosophic positive ideal solution (PIS) and negative ideal solution (NIS): Let Υ_+ and Υ_- denote the PIS and NIS represented as $\Upsilon_+ = \{(c_1, \Upsilon_{+1}), (c_2, \Upsilon_{+2}), ..., (c_n, \Upsilon_{+n})\}$ and $\Upsilon_- = \{(c_1, \Upsilon_{-1}), (c_2, \Upsilon_{-2}), ..., (c_n, \Upsilon_{-n})\}$, where Υ_{+j}, and Υ_{-j} are defined as $\Upsilon_{+j} = (\xi_{+j}, \zeta_{+j}, \kappa_{+j})$ where

$$
(\xi_{+j},\,\zeta_{+j},\,\kappa_{+j}) = \begin{cases} \left(\max\limits_{i=1}^{m}\xi_{ij},\, \min\limits_{i=1}^{m}\zeta_{ij},\, \min\limits_{i=1}^{m}\kappa_{ij}\right) & if\ c_j \in \Psi_B \\ \\ \left(\min\limits_{i=1}^{m}\xi_{ij},\, \max\limits_{i=1}^{m}\zeta_{ij},\, \max\limits_{i=1}^{m}\kappa_{ij}\right) & if\ c_j \in \Psi_C \end{cases} \tag{8}
$$

And $\Upsilon_{-j} = (\xi_{-j},\, \zeta_{-j},\, \kappa_{-j})$ where

$$
(\xi_{-j},\,\zeta_{-j}\ \kappa_{-j}) = \begin{cases} \left(\min\limits_{i=1}^{m}\xi_{ij},\, \max\limits_{i=1}^{m}\zeta_{ij},\, \max\limits_{i=1}^{m}\kappa_{ij}\right) & if\ c_j \in \Psi_B \\ \\ \left(\max\limits_{i=1}^{m}\xi_{ij},\, \min\limits_{i=1}^{m}\zeta_{ij},\, \min\limits_{i=1}^{m}\kappa_{ij}\right) & if\ c_j \in \Psi_C \end{cases} \tag{9}
$$

Definition 7 Type I and type II closeness measures: Let $\mathfrak{C}(\Upsilon_i,\, \Upsilon_+)$ and $\mathfrak{C}(\Upsilon_i,\, \Upsilon_-)$ represent the neutrosophic correlation coefficients for PIS and NIS respectively, for Υ_i. Also, let $\mathfrak{M}_I(\Upsilon_i)$, $\mathfrak{M}_{II}(\Upsilon_i)$ represent the type I and type II closeness measures, respectively, where

$$
\mathfrak{M}_I(\Upsilon_i) = \frac{1-\mathfrak{C}(\Upsilon_i,\, \Upsilon_-)}{2-\mathfrak{C}(\Upsilon_i,\, \Upsilon_+)-\mathfrak{C}(\Upsilon_i,\, \Upsilon_-)} \tag{10}
$$

$$
\mathfrak{M}_{II}(\Upsilon_i) = \frac{1+\mathfrak{C}(\Upsilon_i,\, \Upsilon_+)}{2+\mathfrak{C}(\Upsilon_i,\, \Upsilon_+)+\mathfrak{C}(\Upsilon_i,\, \Upsilon_-)}. \tag{11}
$$

It is assumed that the denominator of equations (10) and (11) is not zero.

Theorem 2 The type I closeness measure $\mathfrak{M}_I(\Upsilon_i)$ for every neutrosophic characteristic Υ_i meet the characteristics listed below:

(i) $0 \le \mathfrak{M}_I(\Upsilon_i) \le 1$

(ii) $\mathfrak{M}_I(\Upsilon_i) = 1$ if $\mathfrak{C}(\Upsilon_i,\, \Upsilon_+) = 1$

(iii) $\mathfrak{M}_I(\Upsilon_i) = 0$ if $\mathfrak{C}(\Upsilon_i,\, \Upsilon_-) = 1$

Proof. For (i), we know that $-1 \le \mathfrak{C}(\Upsilon_i,\, \Upsilon_+) \le 1$ and $-1 \le \mathfrak{C}(\Upsilon_i,\, \Upsilon_-) \le 1$.

So, $0 \le 1-\mathfrak{C}(\Upsilon_i,\, \Upsilon_+) \le 2$ and $0 \le 1-\mathfrak{C}(\Upsilon_i,\, \Upsilon_-) \le 2$ and $0 \le 2-\mathfrak{C}(\Upsilon_i,\, \Upsilon_+)-\mathfrak{C}(\Upsilon_i,\, \Upsilon_-) \le 4$. This proves (i).

The proof of (ii) can be verified using $\mathfrak{C}(\Upsilon_i,\, \Upsilon_+)$ since we have $\mathfrak{C}(\Upsilon_i,\, \Upsilon_+) = 1$. Similarly, (iii) can be proved.

If $\mathfrak{C}(\Upsilon_i,\, \Upsilon_+) = 1$ gives a strong positive relationship, as consequently, type I closeness measure $\mathfrak{M}_I = 1$ gives that the corresponding alternative Υ_i is better than the rest of the alternative. $\mathfrak{C}(\Upsilon_i,\, \Upsilon_-) = 1$ provides a stronger positive relation between Υ_i and Υ_- implies type I closeness measure $\mathfrak{M}_I = 0$, signifies that the alternative Υ_i is inferior.

Theorem 3 The type II closeness measure $\mathfrak{M}_{II}(\Upsilon_i)$ for every neutrosophic characteristic Υ_i possesses the following characteristics:

(i) $0 \le \mathfrak{M}_{II}(\Upsilon_i) \le 1$

(ii) $\mathfrak{M}_{II}(\Upsilon_i) = 0$ if $\mathfrak{C}(\Upsilon_i,\, \Upsilon_+) = -1$

(iii) $\mathfrak{M}_{II}(\Upsilon_i) = 1$ if $\mathfrak{C}(\Upsilon_i,\, \Upsilon_-) = -1$

(iv) $\mathfrak{M}_{II}(\Upsilon_-) \le \mathfrak{M}_{II}(\Upsilon_+)$

Proof. For (i), we know that $-1 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_+) \leq 1$ and $-1 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 1$. So, $0 \leq 1+\mathfrak{C}(\Upsilon_i, \Upsilon_+) \leq 2$ and $0 \leq 1+\mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 2$ and $0 \leq 2+\mathfrak{C}(\Upsilon_i, \Upsilon_+)+\mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 4$. This proves (i).

The proof of (ii) can be verified using $\mathfrak{C}(\Upsilon_i, \Upsilon_+)$ since we have $\mathfrak{C}(\Upsilon_i, \Upsilon_+) = -1$, then $\mathfrak{M}_{II} = 0$.

The proof of (iii) can be verified using $\mathfrak{C}(\Upsilon_i, \Upsilon_-)$ since we have $\mathfrak{C}(\Upsilon_i, \Upsilon_-) = -1$, then $\mathfrak{M}_{II} = 1$.

For (iv), it is known from the previous results that $\mathfrak{C}(\Upsilon_-, \Upsilon_+) = \mathfrak{C}(\Upsilon_+, \Upsilon_-)$ and $\mathfrak{C}(\Upsilon_i, \Upsilon_i) = 1$. Using previous definitions, we have

$$\mathfrak{M}_{II}(\Upsilon_-) = \frac{1+\mathfrak{C}(\Upsilon_-, \Upsilon_+)}{2+\mathfrak{C}(\Upsilon_-, \Upsilon_+)+\mathfrak{C}(\Upsilon_-, \Upsilon_-)} = \frac{1+\mathfrak{C}(\Upsilon_-, \Upsilon_+)}{3+\mathfrak{C}(\Upsilon_-, \Upsilon_+)}$$

$$\mathfrak{M}_{II}(\Upsilon_+) = \frac{1+\mathfrak{C}(\Upsilon_-, \Upsilon_+)}{2+\mathfrak{C}(\Upsilon_+, \Upsilon_+)+\mathfrak{C}(\Upsilon_+, \Upsilon_-)}$$

$$\leq \frac{1+1}{3+\mathfrak{C}(\Upsilon_+, \Upsilon_-)} = \frac{2}{3+\mathfrak{C}(\Upsilon_-, \Upsilon_+)}.$$

As $\mathfrak{C}(\Upsilon_-, \Upsilon_+) \leq 1$, we can conclude that $\mathfrak{M}_{II}(\Upsilon_-) \leq \mathfrak{M}_{II}(\Upsilon_+)$.

Definition 8 Index value: Let ε denote a closeness parameter, where $0 \leq \varepsilon \leq 1$. The neutrosophic correlation-based index value is defined by $\mathscr{I}(\Upsilon_i) = \varepsilon\mathfrak{M}_I(\Upsilon_i)+(1-\varepsilon)\mathfrak{M}_{II}(\Upsilon_i)$. The type I and type II closeness measurements impact the parameter ε. The larger value of ε indicates that neutrosophic correlation closeness $\mathscr{I}(\Upsilon_i)$ would focus on $\mathfrak{M}_I(\Upsilon_i)$ and the smaller value of ε indicates type II focus on $\mathfrak{M}_{II}(\Upsilon_i)$.

Theorem 4 The index value $\mathscr{I}(\Upsilon_i)$ fulfils the following conditions for every neutrosophic characteristic Υ_i in the neutrosophic decision matrix $\mathbb{M}$:

(i) $0 \leq \mathscr{I}(\Upsilon_i) \leq 1$

(ii) $\mathscr{I}(\Upsilon_i) = \mathfrak{M}_I(\Upsilon_i)$ if $\varepsilon = 1$

(iii) $\mathscr{I}(\Upsilon_i) = \mathfrak{M}_{II}(\Upsilon_i)$ if $\varepsilon = 0$

(iv) $\mathscr{I}(\Upsilon_-) \leq \mathscr{I}(\Upsilon_+)$

Definition 9 Weighted type I and type II closeness measures: Suppose the neutrosophic PIS and NIS of the neutrosophic characteristic of an alternative Υ_i be Υ_+, Υ_-. Also, let Υ_i be any neutrosophic characteristic. Let ς_j be the weight of the criteria Ψ_i where $0 \leq \varsigma_j \leq 1$ and $\sum_{j=1}^{n} \varsigma_j = 1$. Let $\mathfrak{M}_I^{\varsigma}(\Upsilon_i)$ and $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i)$ denotes the weighted closeness measure of type I and type II, then

$$\mathfrak{M}_I^{\varsigma}(\Upsilon_i) = \frac{1-\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_-)}{2-\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_+)-\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_-)} \tag{12}$$

$$\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) = \frac{1+\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_+)}{2+\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_+)+\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_-)}. \tag{13}$$

It is assumed that the denominators of equations (12) and (13) are non-zero.

Theorem 5 The weighted type I closeness measure $\mathfrak{M}_I^{\varsigma}(\Upsilon_i)$ satisfies following properties for each neutrosophic characteristic Υ_i in the neutrosophic decision matrix $\mathbb{M}$:

(i) $0 \leq \mathfrak{M}_1^{\varsigma}(\Upsilon_i) \leq 1$

(ii) $\mathfrak{M}_I^{\varsigma}(\Upsilon_i) = 1$ if $\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_+) = 1$

(iii) $\mathfrak{M}_I^{\varsigma}(\Upsilon_i) = 0$ if $\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_-) = 1$

(iv) $\mathfrak{M}_I^{\varsigma}(\Upsilon_-) = 0$ if $\mathfrak{M}_{\mathrm{I}}^{\varsigma}(\Upsilon_+) = 1$

(v) $\mathfrak{M}_I^{\varsigma}(\Upsilon_i) = \mathfrak{M}_I(\Upsilon_i)$ if $\varsigma = (1/n,\ 1/n,\ \ldots,\ 1/n)$

Proof. From previous theorems, we know that $-1 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_+) \leq 1$ and $-1 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 1$. So, $0 \leq 1 - \mathfrak{C}(\Upsilon_i, \Upsilon_+) \leq 2$, $0 \leq 1 - \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 2$ and $0 \leq 2 - \mathfrak{C}(\Upsilon_i, \Upsilon_+) - \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 4$. Therefore, $0 \leq \mathfrak{M}_I^{\varsigma}(\Upsilon_i) \leq 1$. Hence (i) is true.
The proofs of (ii), (iii), (iv), and (v) are obvious.

Theorem 6 The weighted type II closeness measure $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i)$ satisfies following properties for each neutrosophic characteristic Υ_i in the neutrosophic decision matrix $\mathbb{M}$:

(i) $0 \leq \mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) \leq 1$

(ii) $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) = 0$ if $\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_+) = -1$

(iii) $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) = 1$ if $\mathfrak{C}^{\varsigma}(\Upsilon_i, \Upsilon_-) = -1$

(iv) $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_-) \leq \mathfrak{M}_{II}^{\varsigma}(\Upsilon_+)$

(v) $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) = \mathfrak{M}_{II}(\Upsilon_i)$ if $\varsigma = (1/n,\ 1/n,\ \ldots,\ 1/n)$

Proof. From previous theorems, we know that $-1 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_+) \leq 1$ and $-1 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 1$. So, $-2 \leq \mathfrak{C}(\Upsilon_i, \Upsilon_+) + \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 2$ and $0 \leq 2 + \mathfrak{C}(\Upsilon_i, \Upsilon_+) + \mathfrak{C}(\Upsilon_i, \Upsilon_-) \leq 4$. Therefore, $0 \leq \mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) \leq 1$. Hence (i) is true.
The proofs of (ii), (iii), (iv), and (v) are obvious.

Definition 10 Weighted index value: Let ε, $0 \leq \varepsilon \leq 1$ be a closeness parameter, then the weighted index value $\mathscr{I}^{\varsigma}(\Upsilon_i)$ of Υ_i is given by:

$$\mathscr{I}^{\varsigma}(\Upsilon_i) = \varepsilon \mathfrak{M}_I^{\varsigma}(\Upsilon_i) + (1 - \varepsilon)\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i) \tag{14}$$

Theorem 7 The weighted index value $I^{\varsigma}(\Upsilon_i)$ fulfills the following properties for each neutrosophic characteristic Υ_i in the neutrosophic decision matrix $\mathbb{M}$.

(i) $0 \leq \mathscr{I}^{\varsigma}(\Upsilon_i) \leq 1$

(ii) $\mathscr{I}^{\varsigma}(\Upsilon_i) = \mathfrak{M}_I^{\varsigma}(\Upsilon_i)$ if $\varepsilon = 1$

(iii) $\mathscr{I}^{\varsigma}(\Upsilon_i) = \mathfrak{M}_{II}^{\varsigma}(\Upsilon_i)$ if $\varepsilon = 0$

(iv) $\mathscr{I}^{\varsigma}(\Upsilon_-) \leq \mathscr{I}^{\varsigma}(\Upsilon_+)$

(v) $\mathscr{I}^{\varsigma}(\Upsilon_i) = \mathscr{I}(\Upsilon_i)$ if $\varsigma = (1/n,\ 1/n,\ \ldots,\ 1/n)$

Proof. According to equation (13), since both $0 \leq \mathfrak{M}_I \leq 1$ and $0 \leq \mathfrak{M}_{II} \leq 1$ it is evident that $0 \leq \mathscr{I}^{\varsigma}(\Upsilon_i) \leq 1$. This proves (i). It is obvious to prove (ii) and (iii).

For (iv), it is already proven that $\mathfrak{M}_{II}(\Upsilon_-) \leq \mathfrak{M}_{II}(\Upsilon_+)$. Hence, $\mathscr{I}^{\varsigma}(\Upsilon_-) \leq \mathscr{I}^{\varsigma}(\Upsilon_+)$. Similarly, the proof of (v) is valid.

5.1 *Algorithm of the proposed neutrosophic TOPSIS*

The steps of the proposed neutrosophic TOPSIS are as follows:

Step I: Identify m alternatives $\Upsilon = \{\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_m\}$ and n criteria $\Psi = \{\Psi_1, \Psi_2, \ldots, \Psi_n\}$, partitioned into Ψ_B and Ψ_C to contract a MCDM problem.

Step II: Formulate a neutrosophic decision matrix $\mathbb{M} = (m_{ij})_{m \times n}$ (According to equation (2)) using the neutrosophic rating m_{ij} from Table 2.

Step III: Convert the neutrosophic decision matrix $\mathbb{M}$ to a crisp decision matrix using equation (1). Apply the MEREC approach to compute the set of criteria weights $\varsigma = \{\varsigma_1, \varsigma_2, \ldots, \varsigma_n\}$.

Step IV: Normalize the neutrosophic decision matrix $\mathbb{M}$ according to vector normalization and identify the neutrosophic PIS Υ_+ and neutrosophic NIS Υ_- using the equations (8) and (9).

Step V: Compute the membership component $\rho_{\xi}^{\varsigma}(\Upsilon_i, \Upsilon_+)$, $\rho_{\xi}^{\varsigma}(\Upsilon_i, \Upsilon_-)$ and the hesitancy component $\rho_{\zeta}^{\varsigma}(\Upsilon_i, \Upsilon_+)$, $\rho_{\zeta}^{\varsigma}(\Upsilon_i, \Upsilon_-)$ and the non-membership component $\rho_{\kappa}^{\varsigma}(\Upsilon_i, \Upsilon_+)$, $\rho_{\kappa}^{\varsigma}(\Upsilon_i, \Upsilon_-)$ of the weighted correlation coefficient using the equations (5), (6) and (7) for every $\Upsilon_i \in \Upsilon$.

Step VI: Apply equation (4) to calculate the weighted neutrosophic correlation coefficient $\vartheta^{\varsigma}(\Upsilon_i, \Upsilon_+)$ and $\vartheta^{\varsigma}(\Upsilon_i, \Upsilon_-)$ between Υ_i, Υ_+, and Υ_i, Υ_- respectively for every $\Upsilon_i \in \Upsilon$.

Step VII: Use equations (12), (13) to calculate the weighted Type I and Type II closeness measure $\mathfrak{M}_I^{\varsigma}(\Upsilon_i)$ and $\mathfrak{M}_{II}^{\varsigma}(\Upsilon_i)$ for every $\Upsilon_i \in \Upsilon$.

Step VIII: Assign closeness parameter ε, $0 \leq \varepsilon \leq 1$ and compute the weighted index value $\mathscr{I}^{\varsigma}(\Upsilon_i)$ using equation (14) for each $\Upsilon_i \in \Upsilon$.

Step IX: Rank the m options in decreasing order of $\mathscr{I}^{\varsigma}(\Upsilon_i)$ values.

Table 2. Linguistic scale and their SVNS rating

Linguistic Variable	SVNS
Extremely significant (ES)	(0.92, 0.11, 0.12)
Very Significant (VS)	(0.78, 0.21, 0.23)
Significant (S)	(0.64, 0.32, 0.35)
Reasonable (R)	(0.50, 0.50, 0.50)
Insignificant (I)	(0.36, 0.38, 0.68)
Very Insignificant (VI)	(0.22, 0.27, 0.82)
Extremely Insignificant (EI)	(0.11, 0.21, 0.93)

6. Numerical example: Comparison of health coverage company

An MCDM problem is developed so that health insurance providers can examine their performance while considering numerous significant parameters. The proposed neutrosophic correlation-based TOPSIS approach is utilized to solve the MCDM problem.

6.1 *Problem description*

This part addresses a decision-making problem in selecting healthcare assurance providers. An insurance policy is connected to several characteristics, including flexible premium payment choices, a wide range of coverage options, a reputable insurance firm with a high claim settlement ratio, a reasonable premium, and outstanding client feedback. Several researchers work with a variety of these types of criteria. Here are a few criteria often examined in the literature on health insurance. The impact of the criterion premium cost and the number of network hospitals were examined by Ecer and Pamucar [26]. The claim settlement ratio [19] serves as an indicator of the brand strength of any company. Erdebilli et al. [22] examine the criterion brand-strength and analyze its influence on purchasers. Yang et al. [23] work with the criterion of the company's local reputation. The company has many branches that facilitate its operations. The whole amount of assets that the firm has is used to determine its solvency ratio. Gharizadeh et al. [18] work with total assets and several sites. Twelve criteria, including some new ones, have been carefully considered and analyzed for this problem.

Claim settlement ratio (Ψ_1): An insurance provider's efficacy can be assessed by examining its claim settlement ratio, which represents the proportion of settled claims among the total cases filed.

Solvency ratio (Ψ_2): This ratio may be used to assess an organization's capacity to satisfy its future responsibilities and financial liabilities.

Number of network hospitals (Ψ_3): Every insurance provider works in conjunction with several hospitals. Customers will receive the service at the designated number of hospitals at the time of their claim.

Number of branches (Ψ_4): The organization offers its services through branches spread around the world. The number of branches is an essential criterion.

Coverage area (Ψ_5): When travelling or residing in many locations, it is crucial to determine if the insurance company offers nationwide or international coverage.

Renewal process (Ψ_6): The company's renewal procedure is a component that allows them to offer their services. To make it easy for customers, the process should be flexible.

Maternity and pediatric care (Ψ_7): For individuals desiring to have children, the policy provides coverage for maternity care and pediatric services.

limitations (Ψ_8): The supplier's policy is linked to the many limitations and obstacles imposed by the provider.

Premium (Ψ_9): The insurance company must pay the sum to remain eligible for health coverage.

Deductible (Ψ_{10}): A person's out-of-pocket spending for covered medical bills is the deductible. This amount must be paid before insurance begins paying for those expenses.

Claim settlement process (Ψ_{11}): There are various steps in the health insurance claim settlement procedure to get payment for covered medical expenditures. A greater number of steps in the process causes trouble for the clients.

Customer grievance (Ψ_{12}): A grievance is a way for clients to convey their displeasure or complaint with a company's background, service, or goods.

The first seven of the twelve criteria are categorized as beneficial, highlighting their favorable nature or good influence out of the total twelve. On the other hand, the remaining five criteria are classified as non-beneficial, indicating factors that would not favorably impact the evaluation or objective as a whole.

At this point, we are considering twelve HIPs: $\Upsilon = \{\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5, \Upsilon_6, \Upsilon_7, \Upsilon_8, \Upsilon_9, \Upsilon_{10}, \Upsilon_{11}, \Upsilon_{12}\}$ as alternatives for the implementation of our suggested neutrosophic TOPSIS framework in a fuzzy environment.

The description of the providers is as follows: Υ_1: This supplier has a good claim settlement and solvency ratio. However, network hospitals and branches are limited. Υ_2: This supplier has an excellent solvency ratio and handles maternity circumstances. The price of the premium is fair. Υ_3: The claim settlement procedure is lengthy, and the organization has positive relationships with many hospitals. Υ_4: This provider has insufficient numbers of connected hospitals and branches. Care for clients is acceptable. Υ_5: It is good for this provider to have a high solvency ratio and an easy renewal process. Easy settlement and a modest premium attract clients. υ_6: This provider has a high claim settlement ratio and provides excellent pediatric care. This company has a straightforward claim payment method and low pocket spending. Υ_7: This company has a good name but only has a few offices and different places where claims are settled. Υ_8: This provider with many branches has plenty of settlement and solvency ratios. However, there is no flexibility in the renewal procedure. Υ_9: Almost all factors are statistically significant on average. Υ_{10}: Settlement and solvency ratios are acceptable for this provider, whereas the number of branches is unsatisfactory. Υ_{11}: This service has a great name, but the stability ratio is insufficient. Υ_{12}: The corporation has a big branch network. The settlement procedure consists of many phases to accomplish a claim.

6.2 *Solution procedure by the proposed method*

Step I: The twelve HIPs $\Upsilon = \{\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5, \Upsilon_6, \Upsilon_7, \Upsilon_8, \Upsilon_9, \Upsilon_{10}, \Upsilon_{11}, \Upsilon_{12}\}$ are identified and their twelve criteria are $\Psi = \{\Psi_1, \Psi_2, \Psi_3, \Psi_4, \Psi_5, \Psi_6, \Psi_7, \Psi_8, \Psi_9, \Psi_{10}, \Psi_{11}, \Psi_{12}\}$, where $\Psi_B = \{\Psi_1, \Psi_2, \Psi_3, \Psi_4, \Psi_5, \Psi_6, \Psi_7\}$ and $\Psi_C = \{\Psi_8\ \Psi_9, \Psi_{10}, \Psi_{11}, \Psi_{12}\}$.

Step II: The neutrosophic decision matrix $\mathbb{M} = (m_{ij})_{12\times 12}$ is constructed according to equation (2), considering the neutrosophic rating from Table 2.

Step III: With the help of equation (1), the crisp decision matrix be represent as

	Ψ_1	Ψ_2	Ψ_3	Ψ_4	Ψ_5	Ψ_6	Ψ_7	Ψ_8	Ψ_9	Ψ_{10}	Ψ_{11}	Ψ_{12}
Υ_1	0.783	0.895	0.465	0.480	0.663	0.783	0.480	0.440	0.465	0.480	0.663	0.500
Υ_2	0.663	0.783	0.465	0.465	0.500	0.663	0.895	0.663	0.500	0.500	0.895	0.663
Υ_3	0.895	0.663	0.895	0.465	0.663	0.500	0.480	0.663	0.480	0.663	0.895	0.500
Υ_4	0.663	0.480	0.465	0.465	0.480	0.480	0.783	0.783	0.500	0.480	0.663	0.663
Υ_5	0.480	0.783	0.480	0.480	0.500	0.783	0.480	0.663	0.480	0.663	0.480	0.500
Υ_6	0.783	0.663	0.500	0.465	0.500	0.500	0.895	0.500	0.895	0.480	0.480	0.663
Υ_7	0.895	0.663	0.480	0.440	0.663	0.663	0.480	0.500	0.500	0.500	0.895	0.663
Υ_8	0.895	0.783	0.663	0.895	0.500	0.480	0.480	0.500	0.500	0.663	0.663	0.783
Υ_9	0.500	0.663	0.465	0.663	0.663	0.663	0.480	0.500	0.500	0.500	0.895	0.663
Υ_{10}	0.783	0.895	0.465	0.480	0.500	0.500	0.480	0.500	0.500	0.480	0.663	0.500
Υ_{11}	0.783	0.440	0.465	0.663	0.663	0.500	0.480	0.500	0.500	0.500	0.895	0.500
Υ_{12}	0.440	0.500	0.440	0.895	0.500	0.663	0.480	0.500	0.440	0.480	0.895	0.500

Applying MEREC approach, the corresponding criteria weights are as follows: $\varsigma_1 = 0.135$, $\varsigma_2 = 0.123$, $\varsigma_3 = 0.043$, $\varsigma_4 = 0.067$, $\varsigma_5 = 0.045$, $\varsigma_6 = 0.059$, $\varsigma_7 = 0.044$, $\varsigma_8 = 0.103$, $\varsigma_9 = 0.166$, $\varsigma_{10} = 0.068$, $\varsigma_{11} = 0.060$, $\varsigma_{12} = 0.087$.

Step IV: The neutrosophic PIS Υ_+ and the neutrosophic NIS Υ_- are provided in the Table 4.

Step V: The weighted correlation components for membership, hesitant, and non-membership functions of neutrosophic PIN and NIS are shown in the Table 5.

Step VI: Weighted neutrosophic correlation coefficients are computed using equation 4 and provided in Table 6.

Step VII: Weighted type I and type II closeness measures are calculated with the help of equations (12) and (13) and provided in Table 6.

Step VIII: To get the weighted index value, we use $\varepsilon = 0.5$ to lend equal emphasis to type I and type II closeness measures.

Step IX: The ranking order of the twelve alternatives is shown in Table 7, with the index values arranged in decreasing order.

Table 3. Linguistic decision matrix based on neutrosophic rating

Criteria $\Longrightarrow$ / Alternatives $\downarrow$	Ψ_1	Ψ_2	Ψ_3	Ψ_4	Ψ_5	Ψ_6	Ψ_7	Ψ_8	Ψ_9	Ψ_{10}	Ψ_{11}	Ψ_{12}
Υ_1	VS	ES	VI	I	S	VS	I	EI	VI	I	S	R
Υ_2	S	VS	VI	VI	R	S	ES	S	R	R	ES	S
Υ_3	ES	S	ES	VI	S	R	I	S	I	S	ES	R
Υ_4	S	I	VI	VI	I	I	VS	VS	R	I	S	S
Υ_5	I	VS	I	I	R	VS	I	S	I	S	I	R
Υ_6	VS	S	R	VI	R	R	ES	R	ES	I	I	S
Υ_7	ES	S	I	EI	S	S	I	R	R	R	ES	S
Υ_8	ES	VS	S	ES	R	I	I	R	R	S	S	VS
Υ_9	R	S	VI	S	S	S	I	R	R	R	ES	S
Υ_{10}	VS	ES	VI	I	R	R	I	R	R	I	S	R
Υ_{11}	VS	EI	VI	S	S	R	I	R	R	R	ES	R
Υ_{12}	EI	R	EI	ES	R	S	I	R	EI	I	ES	R

Table 4. Neutrosophic PIS Υ_+ and Neutrosophic NIS Υ_-

Solutions	Components	Ψ_1	Ψ_2	Ψ_3	Ψ_4	Ψ_5	Ψ_6	Ψ_7	Ψ_8	Ψ_9	Ψ_{10}	Ψ_{11}	Ψ_{12}
Υ_+	ξ_{+j}	0.370	0.391	0.640	0.522	0.334	0.385	0.494	0.589	0.461	0.623	0.652	0.617
	ζ_{+j}	0.119	0.110	0.103	0.110	0.218	0.157	0.094	0.857	0.925	0.775	0.875	0.854
	κ_{+j}	0.083	0.080	0.048	0.053	0.218	0.145	0.058	0.868	0.942	0.818	0.902	0.844
Υ_-	ζ_{-j}	0.044	0.047	0.076	0.062	0.188	0.177	0.193	0.942	0.936	0.788	0.864	0.755
	ζ_{-j}	0.540	0.499	0.469	0.380	0.340	0.374	0.325	0.659	0.660	0.649	0.567	0.651
	κ_{-j}	0.645	0.619	0.373	0.407	0.424	0.428	0.330	0.466	0.548	0.646	0.445	0.660

The weighted closeness index ε is taken at 0.5 to find the optimal preference order of the alternatives. Since the weighted closeness index $\varepsilon = 0.5$, i.e. the DM gives equal importance to the weighted closeness measure of type I and Type II. The best option is Υ_2, and the worst is Υ_1 according to the proposed neutrosophic TOPSIS approach.

Table 5. Correlation coefficient components for neutrosophic PIS and NIS

Solution	Components	Υ_1	Υ_2	Υ_3	Υ_4	Υ_5	Υ_6	Υ_7	Υ_8	Υ_9	Υ_{10}	Υ_{11}	Υ_{12}
PIS	$\rho_{\zeta}^{\varsigma}(\Upsilon_i, \Upsilon_+)$	-0.691	0.476	0.150	0.231	-0.266	0.600	0.308	0.574	0.381	-0.044	0.158	-0.626
	$\rho_{\xi}^{\varsigma}(\Upsilon_i, \Upsilon_+)$	0.496	0.052	0.360	-0.075	-0.118	0.519	-0.204	-0.228	-0.251	-0.793	-0.442	0.437
	$\rho_{\kappa}^{\varsigma}(\Upsilon_i, \Upsilon_+)$	-0.809	0.676	0.075	0.261	-0.331	0.462	0.494	0.405	0.488	-0.112	0.092	-0.470
NIS	$\rho_{\zeta}^{\varsigma}(\Upsilon_i, \Upsilon_-)$	0.877	-0.621	-0.075	-0.445	0.252	-0.477	-0.410	-0.234	-0.364	-0.027	-0.234	0.639
	$\rho_{\xi}^{\varsigma}(\Upsilon_i, \Upsilon_-)$	-0.212	-0.158	-0.478	0.277	0.440	-0.025	-0.161	-0.028	0.410	0.359	-0.027	-0.105
	$\rho_{\kappa}^{\varsigma}(\Upsilon_i, \Upsilon_-)$	0.478	-0.643	-0.378	0.017	0.444	-0.116	-0.525	-0.254	-0.266	-0.097	0.157	0.556

Table 6. Correlation coefficients and closeness measures

Alternatives	$\vartheta^{\varsigma}(\Upsilon_i, \Upsilon_+)$	$\vartheta^{\varsigma}(\Upsilon_i, \Upsilon_-)$	$\mathfrak{M}_I(\Upsilon_i)$	$\mathfrak{M}_{II}(\Upsilon_i)$
Υ_1	-0.335	0.381	0.317	0.325
Υ_2	0.401	-0.474	0.711	0.727
Υ_3	0.195	-0.310	0.619	0.634
Υ_4	0.139	-0.050	0.550	0.545
Υ_5	-0.238	0.379	0.334	0.356
Υ_6	0.527	-0.206	0.718	0.658
Υ_7	0.199	-0.365	0.630	0.654
Υ_8	0.250	-0.172	0.610	0.602
Υ_9	0.206	-0.074	0.575	0.565
Υ_{10}	-0.317	0.078	0.412	0.388
Υ_{11}	-0.064	-0.034	0.493	0.492
Υ_{12}	-0.220	0.363	0.343	0.364

Table 7. HIP alternative index values and ranking

Alternatives	Υ_1	Υ_2	Υ_3	Υ_4	Υ_5	Υ_6	Υ_7	Υ_8	Υ_9	Υ_{10}	Υ_{11}	Υ_{12}
$\mathscr{I}^{\varsigma}$	0.321	0.719	0.627	0.547	0.345	0.688	0.642	0.606	0.570	0.400	0.493	0.354
Ranking	12	1	4	7	11	2	3	5	6	9	8	10

6.3 *Comparison study*

To test the merit and consistency of the suggested technique, the acquired result is compared to similar methods such as TOPSIS, VIKOR, WASPAS, and COPRAS. We convert the neutrosophic decision matrix to a crisp decision matrix using equation (1) to apply these approaches. The exact weight set of the criteria has been used as the MEREC approach in Step III of Section 6.2 does. For all approaches, we used vector normalization for the similarity of the comparison. Table 8 displays the results of different approaches.

Table 8. Index values of HIP alternatives

Alternatives	Υ_1	Υ_2	Υ_3	Υ_4	Υ_5	Υ_6	Υ_7	Υ_8	Υ_9	Υ_{10}	Υ_{11}	Υ_{12}
TOPSIS	0.38841	0.40229	0.42577	0.33610	0.32161	0.61210	0.40120	0.47126	0.29365	0.39486	0.31522	0.24841
VIKOR	0.92943	0.49704	0.60326	0.33062	0.53614	0.09799	0.59968	0.57092	0.48946	0.66734	0.54316	0.67091
WASPAS	0.39253	0.26313	0.28243	0.19857	0.25639	0.23658	0.30294	0.29179	0.26018	0.32919	0.28101	0.26487
COPRAS	0.48899	0.50490	0.50870	0.48189	0.47831	0.52004	0.49695	0.51899	0.48285	0.48305	0.47542	0.46234
Proposed method	0.32104	0.71908	0.62665	0.54746	0.34495	0.68806	0.64212	0.60566	0.57013	0.39986	0.49262	0.35354

The outcomes displayed in Table 8 indicate that the TOPSIS approach assigned the highest rank to HIP Υ_6 and the lowest rank to HIP Υ_{12}. In both VIKOR and WASPAS, the HIP Υ_1 is deemed the most favourable option; however, variations in the least favourable HIPs exist. HIP Υ_8 is assigned the highest ranking, whereas HIP Υ_{12} is positioned last, aligning with the outcome of the TOPSIS methodology. The proposed neutrosophic TOPSIS method assigns the highest priority to the HIP Υ_2 and the lowest priority to the HIP Υ_1. The TOPSIS method determines the ranking order primarily by the claim settlement ratio for HIP features, maternity and pediatric care, and the claim settlement process. The criteria for ranking orders in the WASPAS and VIKOR approaches are the renewal process and solvency ratio. When ranking HIPs, the COPRAS method considers the following factors: claim settlement ratio, solvency ratio, premium amount, and customer complaints. The suggested method ranks the HIPs while considering the quality of maternity and pediatric treatment, service limits, and indifference to the claim settlement procedure. The index value comparison of the HIPs in these approaches is depicted in Figure 2.

It is visible in Figure 2 that the VIKOR approach exhibits the most significant variation in index values, whereas the COPRAS approach demonstrates the slightest variation. The moderate variation in index values for HIPs between the two TOPSIS approaches demonstrates that the ranking variation of TOPSIS and the proposed neutrosophic TOPSIS are comparable. Considerable variability is evident in the index values of HIP Υ_1 and Υ_6. The HIP with the slightest variation in index values is Υ_{11}, whereas the index values of the remaining HIPs vary to a moderate degree. Despite the similarity in outcomes between the crisp techniques, discernible discrepancies persist in their index values. The potential reason for the discrepancy between the proposed and crisp approaches is that the more comprehensive evaluation criteria merit. Table 9 presents the ranking of the HIP alternatives.

The ranking order of the alternative in the proposed neutrosophic TOPSIS shows that the second alternative Υ_2 ranked top and the first alternative Υ_1 ranked last. The reason is the comparatively better rating of the Υ_2 alternatives in the cost-based criteria than the benefit-based. This fact reveals that customers give more importance to premiums, claim settlement processes, and customer grievances than to claim settlement ratios, company networks, and the number of branches.

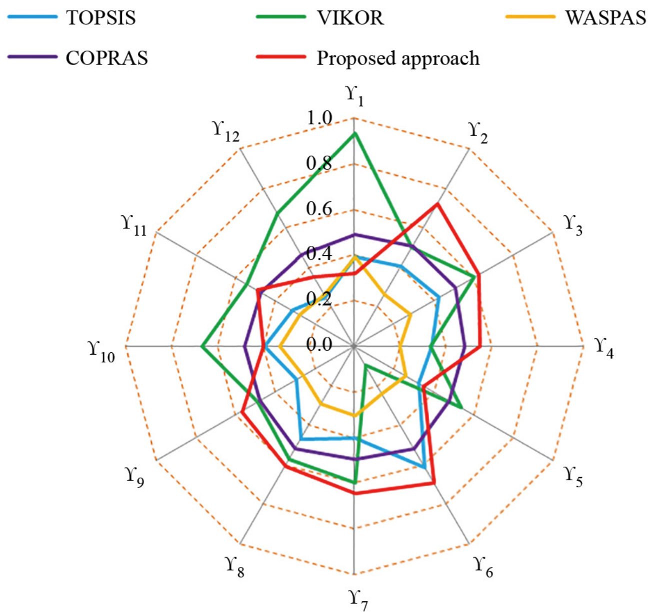

Figure 2. A comparison of index values of the HIPs alternatives

Table 9. Ranking comparison of the suggested and existing approaches

Approach	Results
TOPSIS	$\Upsilon_6 \succ \Upsilon_8 \succ \Upsilon_3 \succ \Upsilon_2 \succ \Upsilon_7 \succ \Upsilon_{10} \succ \Upsilon_1 \succ \Upsilon_4 \succ \Upsilon_5 \succ \Upsilon_{11} \succ \Upsilon_9 \succ \Upsilon_{12}$
VIKOR	$\Upsilon_1 \succ \Upsilon_{12} \succ \Upsilon_{10} \succ \Upsilon_3 \succ \Upsilon_7 \succ \Upsilon_8 \succ \Upsilon_{11} \succ \Upsilon_5 \succ \Upsilon_2 \succ \Upsilon_9 \succ \Upsilon_4 \succ \Upsilon_6$
WASPAS	$\Upsilon_1 \succ \Upsilon_{10} \succ \Upsilon_7 \succ \Upsilon_8 \succ \Upsilon_3 \succ \Upsilon_{11} \succ \Upsilon_{12} \succ \Upsilon_2 \succ \Upsilon_9 \succ \Upsilon_5 \succ \Upsilon_6 \succ \Upsilon_4$
COPRAS	$\Upsilon_6 \succ \Upsilon_8 \succ \Upsilon_3 \succ \Upsilon_2 \succ \Upsilon_7 \succ \Upsilon_1 \succ \Upsilon_{10} \succ \Upsilon_9 \succ \Upsilon_4 \succ \Upsilon_5 \succ \Upsilon_{11} \succ \Upsilon_{12}$
Proposed method	$\Upsilon_2 \succ \Upsilon_6 \succ \Upsilon_7 \succ \Upsilon_3 \succ \Upsilon_8 \succ \Upsilon_9 \succ \Upsilon_4 \succ \Upsilon_{11} \succ \Upsilon_{10} \succ \Upsilon_{12} \succ \Upsilon_5 \succ \Upsilon_1$

6.4 *Sensitivity analysis*

This section assesses the stability of the proposed neutrosophic TOPSIS technique by analyzing the sensitivity of criterion weight determination and closeness parameter variation.

6.4.1 *Criteria weights variation*

The weights derived using CRiteria Importance Through Intercriteria Correlation (CRITIC) [69] and ranking exponent techniques [70, 71] are compared with the weights by the MEREC method. When applying the ranking exponent technique, the decision expert rates each criterion according to the relevance of the criteria as a whole. According to the significance of the criteria, the decision expert must rank each criterion to apply the ranking method. Using Equation (1), the criteria are ranked based on the average SVNS score across every alternative.

Let r_j and ς_j be the rank and weight of the j^{th} criterion, respectively, where $j = 1, 2, 3, ..., n$, then rank exponent weight

$$\varsigma_j = \frac{(n - r_j + 1)^p}{\sum_{j=1}^{n}(n - r_j + 1)^p},\ p \in \Re$$

Table 10 displays the criteria weights determined by MEREC, CRITIC, and rank exponent weight ($p = 0$, 0.5, 1, 2).

Table 10. Criteria weights by several weight determination methods

Criteria	Ψ_1	Ψ_2	Ψ_3	Ψ_4	Ψ_5	Ψ_6	Ψ_7	Ψ_8	Ψ_9	Ψ_{10}	Ψ_{11}	Ψ_{12}
MEREC	0.135	0.123	0.043	0.067	0.045	0.059	0.044	0.103	0.166	0.068	0.060	0.087
CRITIC	0.077	0.066	0.065	0.085	0.095	0.125	0.106	0.059	0.057	0.098	0.092	0.074
$p = 0$	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
$p = 0.5$	0.113	0.108	0.034	0.084	0.076	0.103	0.090	0.068	0.048	0.059	0.118	0.097
$p = 1$	0.141	0.128	0.013	0.077	0.064	0.115	0.090	0.051	0.026	0.038	0.154	0.103
$p = 2$	0.186	0.154	0.002	0.055	0.038	0.125	0.075	0.025	0.006	0.014	0.222	0.098

There is no similarity in the criteria weights between the MEREC and the CRITIC approaches as seen from Table 10. There are three scenarios identified where the criteria weights for p vary depending on the rank-exponent approach. If p increases, the weights of the criteria Ψ_1, Ψ_2, Ψ_6, Ψ_{11}, and Ψ_{12} also increase. The weight of the criteria Ψ_3, Ψ_5, Ψ_8, Ψ_9, and Ψ_{10} decreases when p increases. But the criteria weights of Ψ_4 and Ψ_7 have mixed variation when p increases. Figure 3 shows these variations in weight determination.

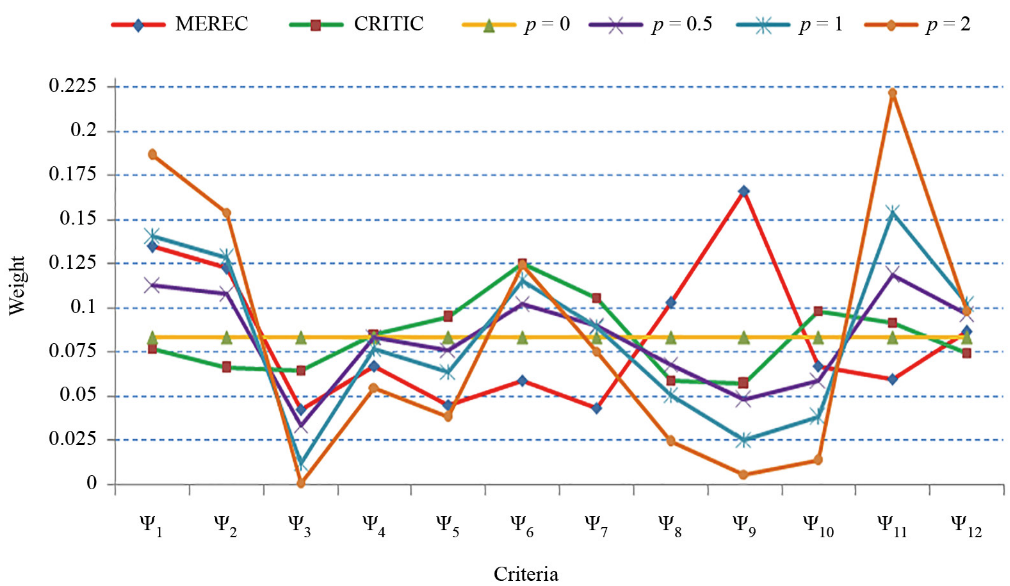

Figure 3. A comparison of the weights of the criterion

The maximum variation in criteria weights is visible from Figure 3 in the rank-exponent approach for $p = 2$. The criteria weights converge to equal weight when p decreases. The criteria weights fluctuate more in the MEREC approach than in the CRITIC approach. The CRITIC method allocates moderate weight to the criteria, whereas the MEREC approach has several ups and downs in the criteria weights. The ranking comparison of the proposed neutrosophic TOPSIS approach for criteria weight variation is shown in Figure 4.

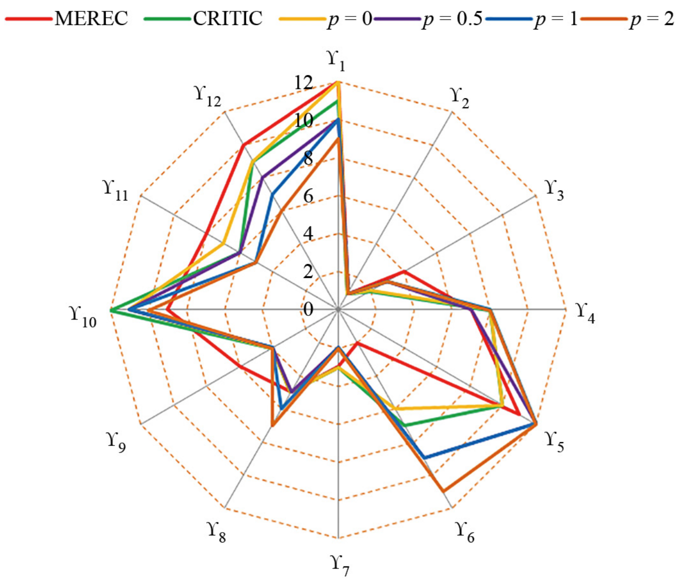

Figure 4. Ranking comparison of the suggested method with varying weight distributions

From Figure 4, it is evident that the ranking of the HIPs is always dominated by the alternative Υ_2 since this HIP consistently ranks first among all the approaches. The second position is obtained by either the seventh or third HIP. The fourth position is almost consistently obtained by Υ_9 HIP. The last phase of the ranking orders is obtained by the HIP alternatives Υ_1, Υ_5, or Υ_{10}. The HIP Υ_5 has maximum fluctuation in ranking from 11th to second. Among these HIPs, the alternatives Υ_2, Υ_7, Υ_4, and Υ_9 have consistency in ranking position among these weight determination processes.

6.4.2 *Closeness parameter variation*

We choose the variation in the closeness parameter ε to check the decision-making in several uncertain situations. The weights of the criteria remain unchanged in this process. The suggested neutrosophic technique is used to establish the HIPs rank sequence, and we observe that the ranking order of the HIPs remains unchanged for ε variation. Table 11 contains an overview of the acquired results.

It is seen from Table 11 that there is a slight variation of the index value $\mathscr{I}^{\varsigma}$ for the variation of ε. Consequently, the ranking sequence of the HIPs is unaffected by ε variation. This scenario happens due to the almost identical values of type I and type II closeness measures. This means the proposed approach slightly depends on DM choices when ranking the alternatives. Figure 5 demonstrates the ranking classification for ε variation.

Table 11. Index values of HIP alternatives for various ε

HIPs	$\varepsilon = 0.1$	$\varepsilon = 0.2$	$\varepsilon = 0.3$	$\varepsilon = 0.4$	$\varepsilon = 0.5$	$\varepsilon = 0.6$	$\varepsilon = 0.7$	$\varepsilon = 0.8$	$\varepsilon = 0.9$
Υ_1	0.324334	0.323512	0.322689	0.321867	0.321044	0.320222	0.319399	0.318577	0.317754
Υ_2	0.725423	0.723839	0.722254	0.720669	0.719085	0.717500	0.715916	0.714331	0.712746
Υ_3	0.632505	0.631041	0.629576	0.628112	0.626647	0.625183	0.623718	0.622253	0.620789
Υ_4	0.545772	0.546194	0.546615	0.547036	0.547457	0.547878	0.548299	0.548720	0.549141
Υ_5	0.353643	0.351470	0.349297	0.347123	0.344950	0.342777	0.340603	0.338430	0.336257
Υ_6	0.663900	0.669939	0.675978	0.682017	0.688056	0.694094	0.700133	0.706172	0.712211
Υ_7	0.651556	0.649196	0.646837	0.644477	0.642118	0.639758	0.637398	0.635039	0.632679
Υ_8	0.602349	0.603177	0.604004	0.604831	0.605659	0.606486	0.607314	0.608141	0.608968
Υ_9	0.566420	0.567348	0.568275	0.569203	0.570131	0.571058	0.571986	0.572913	0.573841
Υ_{10}	0.390324	0.392709	0.395093	0.397478	0.399863	0.402248	0.404633	0.407018	0.409403
Υ_{11}	0.492331	0.492403	0.492476	0.492549	0.492621	0.492694	0.492766	0.492839	0.492912
Υ_{12}	0.361945	0.359845	0.357744	0.355643	0.353543	0.351442	0.349341	0.347240	0.345140

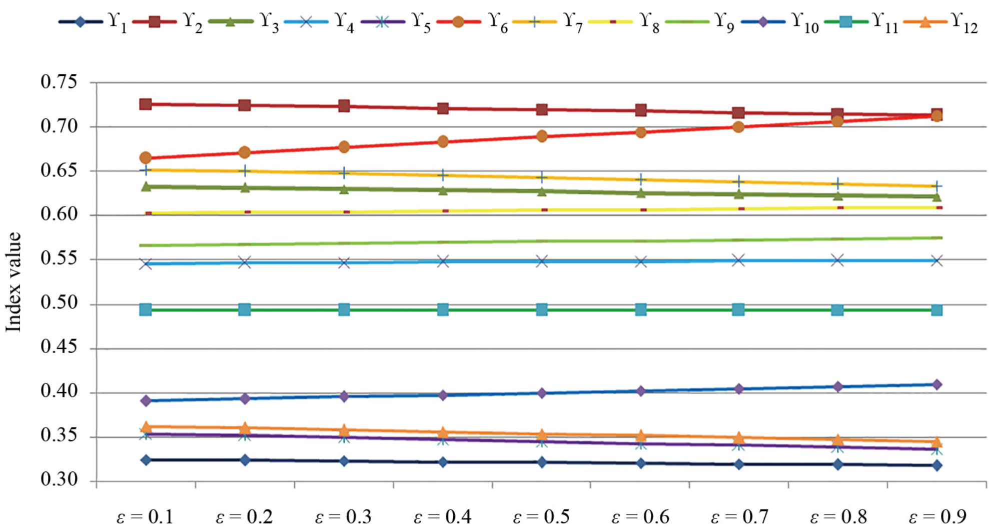

Figure 5. HIP alternatives' index values for different ε

As shown in Figure 5, the index values for most HIPs undergoing ε variation remain unchanged. The index value for HIP Υ_6 exhibits the greatest positive variation; however, this variation is not substantial enough to alter its current ranking order. As ε increases, the index value of HIP Υ_{10} marginally increases, whereas the index values of Υ_5, Υ_7 and Υ_{12} decrease slightly. The ranking positions of the HIP alternatives remain unaffected by this variation.

7. Theoretical and practical contribution

Theoretical contributions in this article include (i) novel neutrosophic correlation coefficients with similar characteristics to classical correlation coefficients. This neutrosophic correlation may be utilized to substitute distance measurements for several MCDM techniques. (ii) An integrated TOPSIS method that incorporates indeterminate information regarding the description of criteria, determination of objective weights, and ranking of alternatives.

The practical implications of this article include (i) health insurance customers' understanding of the characteristics to consider when purchasing health insurance. (ii) The customer is aware of the specific importance of the characteristics of health insurance companies. (iii) The suggested technique assists prospective health insurance customers by giving a ranking of HIPs. (iv) When modifying a plan, the HIP companies may consider client preferences.

8. Conclusion

In this study, we develop a correlation measure of SVNS by considering equal preferences for the components of SVNS. The correlation measure is $[-1, 1]$, corresponding to the traditional correlation coefficient. The weighted closeness measures of type I and type II are proposed based on the weighted correlation measure of the components of SVNS. The weighted closeness index is constructed to extend the TOPSIS technique using weighted closeness measures. The numerical results demonstrate that the proposed approach can solve uncertain MCDM issues. The HIP Υ_2 consistently receives the first position, and Υ_1 acquires the last option. An analysis compared to established methodologies is provided to demonstrate the usefulness and effectiveness of the proposed approach. The sensitivity analysis shows alternative decision-making in uncertain situations.

The suggested methodology offers numerous advantages, including the convergence of the proposed correlation coefficient of SVNS to the classical coefficient, the effective substitution of the distance measure in the TOPSIS approach with the suggested correlation measure, the integration of the weight determination process into the proposed TOPSIS methodology, and the capability of the proposed approach to handle any form of uncertain decision-making problem.

The suggested methodologies have the following limitations: single DM frequently deals with subjective and biased evaluations of the criteria; score function transformation to a crisp decision matrix. Diverse score functions for SVNS can be found in the literature, causing confusion among researchers. Additionally, the closeness parameter is entirely determined by the DM, whose subjectivity may influence the decision-making process.

Based on these limitations, the future research prospects are as follows: The idea of introducing correlation measures may be extended to more powerful fuzzy sets, such as Type II fuzzy sets, hesitant bi-fuzzy sets, complex spherical fuzzy sets, and Diophantine fuzzy sets. In the proposed approach, we determine the criteria of the weights using the MEREC approach, which can be extended by considering either a subjective assessment of the criteria weights or a fuzzy weight determination process. The number of DMs can be increased to make the proposed approach more convenient. A GDM framework can be formulated to solve such decision-making problems by incorporating a panel of DMs. Also, the proposed method can be implemented to solve any real-life MCDM problems, including risk evaluation, green energy selection, supplier selection, the Internet of Things, and renewable energy.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest

The authors declare no competing financial interest.

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