An Autocratic Strategy for Multi-attribute Group Decision Making Based on Neutrosophic Triplets: A Case Study in Prioritizing Recreation Areas in the Tourist Industries

Kuo-Wei LEE

Center for Innovation and Entrepreneurship Education, National Kaohsiung University of Science and Technology, 82445, Taiwan

guowei@nkust.edu.tw

Abstract: Multi-attribute decision making (MADM) as a component of decision science is a significant and essential aspect of engineering planning that may be utilized in a variety of contexts. Due to the complexity of real-life systems, decision-makers (DMs) may encounter several uncertainties throughout the decision-making process. Neutrosophic theory, a generalization of fuzzy set theory and intuitionistic fuzzy set theory, is an efficient tool for dealing with inconsistent, imprecise, and vague values. This paper proposes an autocratic strategy for dealing with multi-attribute group decision-making problems under a neutrosophic environment. The transformation of multiple management decisions and weight matrices into a uniform aggregated assessment matrix is the core aspect of the proposed decision-making strategy. The tourism sector has a unique role on the market and contributes the most to a sustainable economic growth. Due to the picturesque surroundings that may include a green forest, hills, rivers, and marshes, people could often select such a location for relaxation purposes. Therefore, the goal of this paper is to make it possible to choose the best tourist destinations from a range of available options. The proposed method is utilized for prioritizing recreation areas in a tourist industry, where the evaluated values of the attributes for the selected alternatives and the weights of the respective attributes are represented by decision-makers based on single-valued neutrosophic triplets.

Keywords: Neutrosophic sets, Decision making, MAGDM, Autocratic strategy, Tourism management.

1. Introduction

Regarding time and place, experts in decision-making may be cautious about selecting acceptable ranges for evaluating alternative features. Due to the natural world's complexity, decision-makers may encounter difficulties when making decisions with incomplete, imprecise, and ambiguous values. In recent decades, the fuzzy set (FS) theory (Zadeh, 1965) and its applications, such as intuitionistic fuzzy sets (Atanassov, 1986) and interval-valued intuitionistic fuzzy sets (Atanassov 1999), have been suggested as effective tools for dealing with incomplete data. Existing frameworks cannot deal with the imprecise and inconsistent data in real life processes. Smarandache (1998) established the notion of neutrosophic sets (NSs) to overcome such restrictions. As an additional extension of FS theory, NS theory is a potent instrument for dealing with inconsistent, imprecise, and vague values. Many methods for dealing with group decision-making under uncertainty have been introduced in the literature.

To propose a method for solving MAGDM problems under a neutrosophic environment, Pramanik & Mallick (2019) suggested an optimized score function, an updated accuracy function, and a distance function for trapezoidal NNs and then proposed a TODIM approach. Mu et al. (2021) first developed a comparison function based on the membership uncertainty function and the hesitation uncertainty function. Then, they presented a strategy for comparing interval-valued pythagorean fuzzy numbers (IVPFNs) that can discriminate between any pair of IVPFNs. Balin (2020) introduced an extended TOPSIS method based on interval-valued spherical FSs to identify the effective naval ship stabilization system. Krishnan et al. (2021) introduced an approach based on the extension of interval type-2 trapezoidal-fuzzy weighted with zero inconsistency integrated with the VIKOR method for evaluating smart e-tourism data management applications. Nafei et al. (2019) proposed an autocratic MAGDM method based on Interval-valued neutrosophic numbers. Nancy & Garg (2016) first introduced an updated score function for ranking Single-Valued Neutrosophic Numbers (SVNNs). Then, they presented a method for tackling group decision-making problems using the given score function. Kahraman et al. (2022) presented a decision-making technique for assessing the outsourcing option using intuitionistic fuzzy sets, in which the decision-makers' judgments regarding utsourcing alternatives are ambiguous and imprecise. The decision model combines AHP and TOPSIS methods with intuitionistic fuzzy numbers. Nafei et al. (2021) first presented an optimized score function for ranking single-valued neutrosophic

https://doi.org/10.24846/v32i1y202302

numbers. Then, they proposed a TOPSIS method based on the proposed function for neutrosophic decision-making under group recommendation to deal with the hotel location selection problems. By varying the parameter ρ in the Minkowski distance, Rădulescu & Rădulescu (2017) presented a comprehensive TOPSIS approach for ranking cloud service providers. Ardil (2021) proposed a neutrosophic multiple-criteria decision analysis approach for choosing a stealth fighter aircraft. The proposed approach can accommodate situations where decision-making problems involve qualitative variables. Taking advantage of neutrosophic sets, Farid et al. (2022) introduced some novel aggregation operators for information fusion of SVNNs to handle multi-criteria group decision-making challenges. Debnath (2022) first introduced the notion of fuzzy quadripartitioned neutrosophic soft matrix (FQNSM) theory to generalize the FNSM concept and then developed a decision-making model based on FQNSMs. In order to initiate the complex single-valued neutrosophic (CSVN) setting and to determine its important algebraic laws, Mahmood and Ali (2022) elaborated the principle of CSVN PMM (CSVNPMM) operator and CSVN prioritized dual Muirhead mean (CSVNPDMM) operator. Alzahrani et al. (2023) have created a framework for choosing sites for women's universities in several underdeveloped regions of the Indian state of West Bengal. This model included many forms of uncertainty associated with site selection. For the identification of venues, ten crucial criteria were determined. To represent the ambiguity of the situation, trapezoidal neutrosophic number and the Multi-criteria Decision Making tool Analytic Hierarchy Process (AHP) were used for calculating the weights of the selected criteria. The sites were then ranked using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and COmplex PRoportional ASsessment (COPRAS). Shahzadi et al. (2023) offered the robust framework of single-valued neutrosophic soft competition trees by combining the robust approach of a single-valued neutrosophic soft set with a contest graph. In this regard, innovative notions, including single-valued neutrosophic soft k-competition graphs and p-competition single-valued neutrosophic soft graphs, were developed for handling the varying degrees of potential interaction between items in the existence of parameter estimation.

It is always essential to consider the problem's circumstances and choose an appropriate decision-making approach. Although the final order can be obtained using different decision-making methods, the inappropriate use of some methods, regardless of the conditions of the problem, increases the computational complexity and subsequently has an adverse effect on the final result. But the fundamental issue in question is how to handle business and organizational problems that are decided by a single person or a small group of people. The autocratic method for solving group decision-making problems is one of the effective methods that has attracted particular attention in recent years. Also, this method has been employed for solving various decision-making problems based on fuzzy sets and their extensions. Based on the research in the literature and the findings of this analysis, the benefits of the autocratic method can be obtained as follows:

1. Reducing time complexity in the decision-making process; The absence of resistance allows the leaders to make choices more quickly and in a simpler manner. When having to make judgments rapidly, this might be advantageous. These scenarios include perilous or very stressful ones that call for a leader to take control.

2. Easier Goal Setting; When a single person or a small group of like-minded individuals sets objectives, it is simple to concentrate and provide direction. In this situation, the likelihood of having defined structures and plans is significant.

3. Clarity in Line of Authority; Autocracy clarifies who is in control and minimizes misunderstanding or getting commands from several sources. This enables people in positions of authority to provide guidance and issue instructions without encountering competing viewpoints on the same problem.

4. A reasonable justification that explains individual decisions.

Considering the importance of the score function in the decision-making process based on neutrosophic data, in this paper a suitable approach was first chosen for ranking neutrosophic triplets. Then, an autocratic algorithm for solving MAGDM under a neutrosophic environment is presented. The method is utilized for prioritizing recreation areas in a tourist industry.

The contributions of this study are the following:

i. Introducing a new autocratic method for MAGDM based on SVNFSs. The introduced method determines how decision-makers' weights should change until their general agreement level is higher or comparable with a predetermined threshold level.

ii. Presenting a multi-attribute strategy for selecting the best recreation areas in a tourist industry. Choosing the most appropriate tourist site is crucial for visitors. However, it is difficult to determine the most suitable option from among alternatives that feature different advantages. For such a project, a specialized group was created. The advisory group defined the qualities to be included in the framework.

iii. Presenting a simple algorithm for ranking SVNNs that reduces the computational complexity.

The remainder of this paper is structured as follows. Section 2 presents the fundamental concepts and characteristics of NSs. Section 3 sets forth a strategy for ranking SVN values. Section 4 presents a new autocratic method for solving multi-attribute group decision-making problems based on SVNSs. Section 5 describes the implementation of the proposed algorithm for selecting the best recreation areas in a tourist industry. Section 6 presents a sensitivity analysis for the proposed algorithm. Finally, Section 7 includes the conclusion of this paper.

2. Preliminaries

This section describes the essential SVNS-related concepts applicable to this investigation.

Definition 1 (Smarandache, 2005): A NS N in O is defined by $X_N : O \to \left]0^-, 1^+\right[$, $Y_N : O \to \left]0^-, 1^+\right[$ and $Z_N : O \to \left]0^-, 1^+\right[$ which represent the truth, indeterminacy, and falsity membership functions, respectively. Such that $0^- \le X_N(o) + Y_N(o) + Z_N(o) \le 3^+, \forall o \in O$.

Definition 2 (Nafei, Gu & Yuan, 2021): Assume that N and M are two neutrosophic sets. For all $o \in O$, N is contained in M, if and only if:

$$Sup\, X_N(o) \le Sup\, X_M(o),$$
$$Inf\, X_N(o) \le Inf\, X_M(o),$$
$$Sup\, Y_N(o) \ge Sup\, Y_N(o),$$
$$Inf\, Y_N(o) \ge Inf\, Y_N(o),$$
$$Sup\, Z_N(o) \ge Sup\, Z_N(o),$$
$$Inf\, Z_N(o) \ge Inf\, Z_N(o).$$

Definition 3 (Smarandache, 2005): A SVNS N in X is denoted by $N = \{o, X_N(o), Y_N(o), Z_N(o); o \in X\}$, where $X_N : O \to [0,1]$, $Y_N : O \to [0,1]$ and $Z_N : O \to [0,1]$ and also $0 \le X_N(o) + Y_N(o) + Z_N(o) \le 3, \forall o \in O$. $X_N(o)$, $Y_N(o)$ and $Z_N(o)$ represent the degree of truth, indeterminacy and falsity membership functions of o to N, respectively.

Definition 4 (Wang et al., 2010): For a SVNS N, the trinary $(X_N(o), Y_N(o), Z_N(o))$ can be considered as a Neutrosophic Triplet Number (NTN). For convenience, the triplet $(X_N(o), Y_N(o), Z_N(o))$ is often denoted by (X, Y, Z).

Definition 5: The arithmetic operators between two NTNs $e = (X_1, Y_1, Z_1)$ and $f = (X_2, Y_2, Z_2)$ are defined as follows:

$$e \oplus f = \begin{pmatrix} X_1 + X_2 - X_1 X_2, \\ Y_1 Y_2,\ Z_1 Z_2 \end{pmatrix}, \quad (1)$$

$$e \otimes f = \begin{pmatrix} X_1 X_2,\ Y_1 + Y_2 - Y_1 Y_2, \\ Z_1 + Z_2 - Z_1 Z_2 \end{pmatrix}, \quad (2)$$

$$e \ominus f = \left(\frac{X_1 - X_2}{1 - X_2}, \frac{Y_1}{Y_2}, \frac{Z_1}{Z_2} \right), \quad (3)$$

$$e \oslash f = \left(\frac{X_1}{X_2}, \frac{Y_1 - Y_2}{1 - Y_2}, \frac{Z_1 - Z_2}{1 - Z_2} \right), \quad (4)$$

$$\lambda e = \left(1 - (1 - X_1)^{\lambda}, Y_1^{\lambda}, Z_1^{\lambda}\right), \quad \lambda > 0, \quad (5)$$

$$e^{\lambda} = \left(X_1^{\lambda}, 1 - (1 - Y_1)^{\lambda}, 1 - (1 - Z_1)^{\lambda}\right), \quad \lambda > 0. \quad (6)$$

Definition 6 (Smarandache, 2004): The complement of a SVNS N can be represented by N^c and is defined by $X_N^c(o) = Z_N(o)$, $Y_N^c(o) = 1 - Y(o)$, $Z_N^c(o) = X_N(o)$ for all $o \in O$. So, $N^c = \{o, Z_N(o), 1 - Y_N(o), X_N(o); o \in X\}$.

Definition 7 (Mukherjee et al., 2022): In mathematical or statistical programming, a threshold classifier is any model in which a threshold value or collection of threshold values is used to distinguish ranges of values for which the behavior predicted by the employed model differs significantly.

Definition 8: In decision-making and other social sciences, preference refers to the ranking of alternatives by an individual based on their relative usefulness, a procedure that leads to an "optimal selection" (whether real or theoretical). Preferences are evaluations that often pertain to considerations of significance in connection to practical reasoning.

3. Single-Valued Neutrosophic Score, Accuracy, and Certainty Functions

Several functions have been introduced in the literature to rank NTNs. Şahin (2014) proposed a score function and an accuracy function that can be used alternatively for NTNs. However, in some particular cases, both proposed functions are unable to present a ranking order for sorting the numbers. In this regard, to overcome the existing limitations, Nancy & Garg (2016) proposed an optimized score function. By pointing out the shortcomings of Nancy & Garg's method in sorting neutrosophic triplet numbers (NTNs) in some other exceptional cases, Nafei, Gu & Yuan (2021) proposed another score function for ranking the NTNs as follows:

Definition: Assume that $e=(X\ ,\ Y\ ,\ Z\ )$ be a set of SVNNs. The score function S for ranking SVNNs could be defined as:

$$AZ\,(e)=\frac{(4+X\ -2Y\ -Z\ )(2-Y\ )(2-Z\ )}{5}. \quad (7)$$

The introduced Score function is beneficial and can considerably rank neutrosophic numbers. However, since there exists an equation with three variables, from a mathematical point of view, it's still possible to find different numbers that may have the same score value. Based on such logic, Smarandache (2020), by suggesting a score function, $S\,(e)=\frac{2+X\ -Y\ -Z}{3}$, an accuracy function $A\,(e)=X\ -Z$, and a certainty function, $C\,(e)=X$ proposed an algorithm for obtaining an order or SVNNs as follows:

1. Apply the neutrosophic score function S for ranking SVNNs.

If $S\,(X_1,Y_1,Z_1)=S\,(X_2,Y_2,Z_2)$ then apply the neutrosophic accuracy function.

2. If $A\,(X_1,Y_1,Z_1)=A\,(X_2,Y_2,Z_2)$ then apply the neutrosophic certainty function.

3. By applying the certainty function C,

i. if $C\,(X_1,Y_1,Z_1)>C\,(X_2,Y_2,Z_2)$, then $X_1,Y_1,Z_1>X_2,Y_2,Z_2$.

ii. if $C\,(X_1,Y_1,Z_1)<C\,(X_2,Y_2,Z_2)$, then $X_1,Y_1,Z_1<X_2,Y_2,Z_2$.

Using three functions that can be employed interchangeably will surely solve the ranking problems. But it is reasonable that in order to reduce the complexity of calculations, one should always look for an approach for reaching the desired solution with the least amount of computation. However, the score function introduced by Smarandache is simple. It is easy to find many pairs of numbers that cannot be ranked by this function, which makes it necessary to use alternative functions. In order to minimize the use of alternative functions and to maintain the algorithm in such a way as to be sure of obtaining the final order, an improved algorithm was proposed here. Therefore, the suggested idea is first to use the score function AZ introduced by Nafei et al. (2021). If this function is not available to rank the NNs, the accuracy and certainty functions introduced by Smarandache (2020) should be used as follows:

1. Apply the neutrosophic score function AZ for ranking SVNNs.

If $AZ\,(X_1,Y_1,Z_1)=AZ\,(X_2,Y_2,Z_2)$, then apply the neutrosophic accuracy function.

2. If $A\,(X_1,Y_1,Z_1)=A\,(X_2,Y_2,Z_2)$, then apply the neutrosophic certainty function.

3. By applying the certainty function C

i. if $C\,(X_1,Y_1,Z_1)>C\,(X_2,Y_2,Z_2)$ then $X_1,Y_1,Z_1>X_2,Y_2,Z_2$.

ii. if $C\,(X_1,Y_1,Z_1)<C\,(X_2,Y_2,Z_2)$ then $X_1,Y_1,Z_1<X_2,Y_2,Z_2$.

By using the proposed algorithm, the possibility of using alternative functions will be reduced and subsequently, the increase in complexity and errors in calculations will be prevented.

4. A New GMADM Method Based on SVNSs

Let us assume that there exist X alternatives, Y attributes, and C decision-makers. Also, the decision matrix θ_c given by D_c demonstrates the evaluated values of alternatives for attributes as follows:

$$\theta_c = \begin{array}{c} \\ \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_X \end{array} \begin{array}{c} \begin{array}{cccc} \beta_1 & \beta_2 & \cdots & \beta_Y \end{array} \\ \begin{bmatrix} \lambda_{11}^c & \lambda_{12}^c & \dots & \lambda_{1Y}^c \\ \lambda_{21}^c & \lambda_{22}^c & \dots & \lambda_{2Y}^c \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_{X1}^c & \lambda_{X2}^c & \dots & \lambda_{XY}^c \end{bmatrix} \end{array}. \quad (8)$$

One should suppose that $\breve{w}_c = [\breve{w}_1^c, \breve{w}_2^c, ..., \breve{w}_Y^c]$ is a weight vector given by D_c for attributes based on SVNNs. Also, $W_c^{(r)}$ represent the weights of decision makers (DMs) D_c at the r[th] row, where $W_c^{(r)} \in [0,1]$ and $\sum_{c=1}^{C} W_c = 1$.

The proposed algorithm for solving the above problem is presented as follows:

Step 1. Create a weighted evaluation matrix ω_c using the multiplication operator presented in equation (2):

$$\omega_c = \begin{array}{c} \\ \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_X \end{array} \begin{array}{c} \begin{array}{cccc} \beta_1 & \beta_2 & \dots & \beta_Y \end{array} \\ \begin{bmatrix} \lambda_{11}^c \otimes \breve{w}_1^c & \lambda_{12}^c \otimes \breve{w}_2^c & \dots & \lambda_{1Y}^c \otimes \breve{w}_Y^c \\ \lambda_{21}^c \otimes \breve{w}_1^c & \lambda_{22}^c \otimes \breve{w}_2^c & \dots & \lambda_{2Y}^c \otimes \breve{w}_Y^c \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_{X1}^c \otimes \breve{w}_1^c & \lambda_{X2}^c \otimes \breve{w}_2^c & \dots & \lambda_{XY}^c \otimes \breve{w}_Y^c \end{bmatrix} \end{array} =$$

$$\begin{bmatrix} \gamma_{11}^c & \gamma_{12}^c & \cdots & \gamma_{1Y}^c \\ \gamma_{21}^c & \gamma_{22}^c & \cdots & \gamma_{2Y}^c \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{X1}^c & \gamma_{X2}^c & \cdots & \gamma_{XY}^c \end{bmatrix}. \quad (9)$$

where $\gamma_{xy}^c = \lambda_{xy}^c \otimes \breve{w}_y^c$ such that $1 \le x \le X$ and $1 \le y \le Y$.

Step 2. Utilize the combination of functions indicated in equation (1) to generate the accumulated grading matrix.

$$\vartheta = \begin{array}{c} \\ \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_X \end{array} \begin{array}{c} \begin{array}{cccc} D_1 & D_2 & \cdots & D_C \end{array} \\ \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1C} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{X1} & \rho_{X2} & \cdots & \rho_{XC} \end{bmatrix} \end{array}. \quad (10)$$

where $\rho_{xc} = \gamma_{x1}^c \oplus \gamma_{x2}^c \oplus \cdots \oplus \gamma_{xY}^c$.

Step 3. Considering the algorithm for ranking the neutrosophic triplets, generate the feature matrix δ as follows:

$$\delta(\vartheta) = \begin{array}{c} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_X \end{array} \begin{bmatrix} S(\rho_{11}) & S(\rho_{12}) & \cdots & S(\rho_{1C}) \\ S(\rho_{21}) & S(\rho_{22}) & \cdots & S(\rho_{2C}) \\ \vdots & \vdots & \ddots & \vdots \\ S(\rho_{X1}) & S(\rho_{X2}) & \cdots & S(\rho_{XC}) \end{bmatrix}. \quad (11)$$

Step 4. Using the classification method described in Definition 2 create the preferential vectors π^c for each alternative.

$$\pi^c = \begin{array}{c} \begin{array}{ccc} \alpha_k^c & \alpha_{k-1}^c & \dots \ \alpha_{k-X}^c \end{array} \\ [\varepsilon_1^c \quad \varepsilon_2^c \quad \dots \quad \varepsilon_X^c] \end{array}. \quad (12)$$

Step 5. Calculate the aggregated score value $\varphi_x = \sum_{c=1}^{C} \left(W_c^{(r)} \times \delta(\rho_{xc}) \right)$, of all alternatives and then create a group prioritization vector as follows:

$$\kappa = \begin{array}{c} \begin{array}{ccc} \alpha_1 & \alpha_2 & \cdots \ \alpha_X \end{array} \\ [t_1 \quad t_2 \quad \dots \quad t_X] \end{array}. \quad (13)$$

Step 6. Obtain the similarity degrees between π^c and κ. In this case for $t_x \in \kappa$ and $\varepsilon_x^c \in \pi^c$, if $t_x \ne \varepsilon_x^c$, then $S(\pi^c, \kappa) = 0$. Otherwise, if $t_x = \varepsilon_x^c = j$, then, $S(\pi^c, \kappa) = S(\pi^c, \kappa) + [X - (j-1)]$.

Step 7. Establish the group consensus degree $\partial^{(r)}$ of all DMs at the r[th] row as follows:

$$\partial^{(r)} = \sum_{c=1}^{C} \left(\sigma_c \times W_c^{(r)} \right), \quad (14)$$

where

$$\sigma_c = \frac{S(\pi^c, \kappa)}{S(\pi^1, \kappa) + S(\pi^2, \kappa) + \dots + S(\pi^C, \kappa)}, \quad (15)$$

If $\partial^{(r)} < T$ where $T \in [0,1]$ is the group decisive agreement threshold value, t hen go to step 8. Otherwise, the largest φ_x of alternative α_x concerning all decision-makers in step 5, has the best preference order of alternative α_x .

Step 8. Adjust the decision-maker's frequency as described below:

$$W_c^{(r+1)} = \frac{\psi_c^{r+1}}{\sum_{c=1}^{C} \psi_c^{r+1}}, \quad (16)$$

where $\psi^{r+1} = W_c^{(r)} \times (1+\sigma_c)$.

Then let $(r = r+1)$ and return to step 5.

The above algorithm will be illustrated in the next section to explore the performance of the suggested method.

5. Numerical Example

The main purpose of this paper is to evaluate potential approaches and create frameworks to aid judgment calls in prioritizing tourist areas. Selecting the most appropriate tourist site is crucial for visitors. However, it is difficult to determine the most suitable option among alternatives that feature different advantages. For such a project, a specialized group of experts was created in the tourism industry. The advisory group defined the qualities to be included in the chosen framework. Let us suppose that the technical group consists of three experts. Four tourist sites were considered as alternatives. This evaluation also considered safety, accessibility, and affordability as the attributes of this analysis. By stating the features of the neutrosophic theory, experts were asked to express their opinions based on the neutrosophic numbers. The comparison matrices provided by the experts are presented as follows:

Table 1. Decision values as given by D_1

	Safety	Accessibility	Affordability
Site 1	[0.2,0.9, 0.3]	[0.7, 0.9, 0.8]	[0.2, 0.2, 0.0]
Site 2	[0.0,0.2, 1.0]	[0.4, 0.8, 0.5]	[0.5, 0.9, 0.1]
Site 3	[0.5, 0.1, 0.5]	[0.3, 0.5, 0.7]	[0.4, 0.6, 0.6]
Site 4	[0.4, 0.4, 0.4]	[0.4, 0.1, 0.1]	[0.1, 0.7, 0.0]

Table 2. Decision values as given by D_2

	Safety	Accessibility	Affordability
Site 1	[0.4, 0.4,0.1]	[0.4, 0.6, 0.2]	[0.5, 0.3, 0.7]
Site 2	[0.4, 0.8,0.5]	[0.5, 0.4, 1.0]	[0.5, 0.6, 0.0]
Site 3	[0.7, 0.4,0.4]	[0.3, 0.9,0.7]	[0.5, 0.3, 0.5]
Site 4	[0.6, 0.7,0.8]	[0.8, 0.1,0.6]	[0.3, 0.5, 1.0]

Table 3. Decision values as given by D_3

	Safety	Accessibility	Affordability
Site 1	[0.4, 0.1, 0.5]	[0.5, 0.8, 0.9]	[0.1, 0.2, 1.0]
Site 2	[0.2, 0.2, 0.6]	[0.7, 0.7, 0.0]	[0.9, 0.3, 0.6]
Site 3	[0.4, 0.0,0.5]	[0.8, 0.4, 0.5]	[0.5, 0.4, 0.7]
Site 4	[0.3, 0.6, 0.3]	[0.3, 0.2, 0.7]	[0.2, 0.3, 0.4]

Let us suppose that the attribute weights are given by three different experts as follows:

Table 4. Given weights for the chosen attributes

	Safety	Accessibility	Affordability
D_1	[0.8, 0.2, 0.1]	[0.4, 0.3, 0.5]	[0.3, 0.3, 0.1]
D_2	[0.9, 0.6, 0.3]	[0.2, 0.4, 0.1]	[0.7, 0.4, 0.6]
D_3	[0.6, 0.4, 0.7]	[0.2, 1.0, 0.3]	[1.0, 0.2, 0.6]

The proposed algorithm for solving the above problem is as follows:

Step 1. Create a weighted evaluation matrix using the multiplication operator presented in equation (2) as follows:

$$\omega_1 = \begin{array}{c} \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{array} \begin{array}{ccc} \beta_1 & \beta_2 & \beta_3 \\ \end{array} \begin{bmatrix} [0.16,\ 0.94, 0.51] & [0.14, 0.93, 0.86] & [0.02, 0.60, 0.10] \\ [0.00, 0.52, 1.00] & [0.08, 0.86, 0.65] & [0.05, 0.95, 0.19] \\ [0.40, 0.46, 0.65] & [0.06, 0.65, 0.79] & [0.04, 0.80, 0.64] \\ [0.32, 0.64, 0.58] & [0.08, 0.37, 0.37] & [0.01, 0.85, 0.10] \end{bmatrix},$$

$$\omega_2 = \begin{array}{c} \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{array} \begin{array}{ccc} \beta_1 & \beta_2 & \beta_3 \\ \end{array} \begin{bmatrix} [0.36, 0.52, 0.73] & [0.24, 0.76, 0.52] & [0.15, 0.37, 0.88] \\ [0.36, 0.84, 0.85] & [0.30, 0.64, 1.00] & [0.15, 0.64, 0.60] \\ [0.63, 0.52, 0.82] & [0.18, 0.94, 0.82] & [0.15, 0.37, 0.80] \\ [0.54, 0.76, 0.94] & [0.48, 0.46, 0.76] & [0.09, 0.55, 1.00] \end{bmatrix},$$

$$\omega_3 = \begin{array}{c} \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{array} \begin{array}{ccc} \beta_1 & \beta_2 & \beta_3 \\ \end{array} \begin{bmatrix} [0.24, 0.28, 1.00] & [0.2, 1.00\ , 0.92] & [0.07, 0.44, 1.00] \\ [0.12, 0.36, 1.00] & [0.28, 1.00, 0.20] & [0.63, 0.51, 0.84] \\ [0.24, 0.20, 1.00] & [0.32, 1.00, 0.60] & [0.35, 0.58, 0.88] \\ [0.18, 0.68, 1.00] & [0.12, 1.00, 0.76] & [0.14, 0.51, 0.76] \end{bmatrix},$$

Step 2. Utilize the combination of functions indicated in equation (1) to generate the accumulated grading matrix.

$$\vartheta = \begin{matrix} & \beta_1 & \beta_2 & \beta_3 \\ \alpha_1 & [0.30, 0.53, 0.05] & [0.28, 1.00, 0.44] & [1.00, 0.92, 1.00] \\ \alpha_2 & [0.13, 0.43, 0.13] & [0.36, 1.00, 0.51] & [1.00, 0.20, 0.84] \\ \alpha_3 & [0.46, 0.24, 0.33] & [0.20, 1.00, 0.58] & [1.00, 0.60, 0.88] \\ \alpha_4 & [0.38, 0.20, 0.03] & [0.68, 1.00, 0.51] & [1.00, 0.76, 0.76] \end{matrix}.$$

Step 3. By using the algorithm for ranking the neutrosophic triplets presented in Section 3, generate the feature matrix δ as follows:

$$\delta(\vartheta) = \begin{bmatrix} 1.84670527 & 2.44597458 & 1.32487546 \\ 1.86381334 & 1.68819273 & 2.81543242 \\ 2.14923405 & 2.04399392 & 2.16539641 \\ 2.81620647 & 1.71203301 & 1.46180501 \end{bmatrix}.$$

Step 4. Using the classification method described in Definition 8, create the preferential vectors π^c for each alternative.

$$\pi^1 = [4,\ 3,\ 2,\ 1],$$
$$\pi^2 = [1,\ 3,\ 4,\ 2],$$
$$\pi^3 = [2,\ 3,\ 4,\ 1].$$

Step 5. Calculate the aggregated score value of all alternatives as follows:

$$\varphi_1 = 1.97430308,\ \varphi_2 = 1.90628907,$$
$$\varphi_3 = 2.11927825,\ \varphi_4 = 2.34951429.$$

Therefore, the group prioritization vector can be created as follows:

$$\kappa = [4\ \ 3\ \ 1\ \ 2].$$

Step 6. Obtain the similarity degrees between π^1, π^2, π^3 and κ.

$$S\left(\pi^1, \kappa\right) = \left[4 - (4-1)\right] + \left[4 - (3-1)\right] = 3,$$
$$S\left(\pi^2, \kappa\right) = \left[4 - (3-1)\right] + \left[4 - (2-1)\right] = 5,$$
$$S\left(\pi^3, \kappa\right) = \left[4 - (3-1)\right] = 2.$$

Step 7. Establish the collective majority consensus grade $\partial^{(1)}$ of all DMs at the first row as follows:

$$\sigma_1 = \frac{3}{3+5+2} = 0.3,$$
$$\sigma_2 = \frac{5}{3+5+2} = 0.5,$$
$$\sigma_3 = \frac{2}{3+5+2} = 0.2.$$

So, $\partial^{(1)} = (0.6 \times 0.3) + (0.3 \times 0.2) + (0.1 \times 0.5) = 0.29.$

Assume $T = 0.6$. Since $0.29 < T$, one should go to the next step. Otherwise, the largest φ_x in step 5 has the best preference order of alternative α_x .

Step 8. Adjust the decision-maker's frequency.

$$\psi_1^2 = 0.6 \times (1 + 0.3) = 0.78,$$
$$\psi_2^2 = 0.3 \times (1 + 0.2) = 0.36,$$
$$\psi_3^2 = 0.1 \times (1 + 0.5) = 0.15.$$

Therefore,

$$W_1^{(2)} = \frac{0.78}{1.29} = 0.6047,$$

$$W_2^{(2)} = \frac{0.36}{1.29} = 0.2791,$$

$$W_3^{(2)} = \frac{0.15}{1.29} = 0.1163.$$

Then return to step 5.

By repeating this cycle, the proposed algorithm finally reached the final solution after ten iterations. Where,

$$\varphi_1 = 2.37564932,\ \varphi_2 = 1.71709781,$$
$$\varphi_3 = 2.05556007,\ \varphi_4 = 1.8175554.$$

Because $\varphi_1 > \varphi_3 > \varphi_4 > \varphi_2$, it can be concluded that the order of priority for the selected tourist sites is Site 1, Site 3, Site 4, and finally Site 2.

6. Sensitivity Analysis

A crucial step of each MAGDM method is investigating the weights of decision-makers and their effect on the ranking of alternatives. Therefore, the purpose of this section is to present a detailed and comprehensive sensitivity analysis by defining different scenarios.

As it is shown in Figure 1, the weight of the DMs has changed in each iteration, and the final weights are determined in the seventh iteration. Although the weight of decision-makers changed in each iteration, they always maintained the necessary condition $\sum_{g=1}^{n} W_g = 1$, and although the weight of the decision-makers changed in each iteration, the preference order of decision-makers remained constant after five iterations.

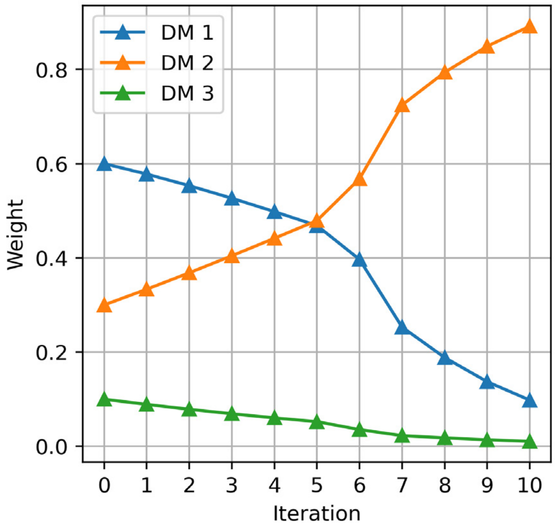

Figure 1. Changes in the weight of decision-makers

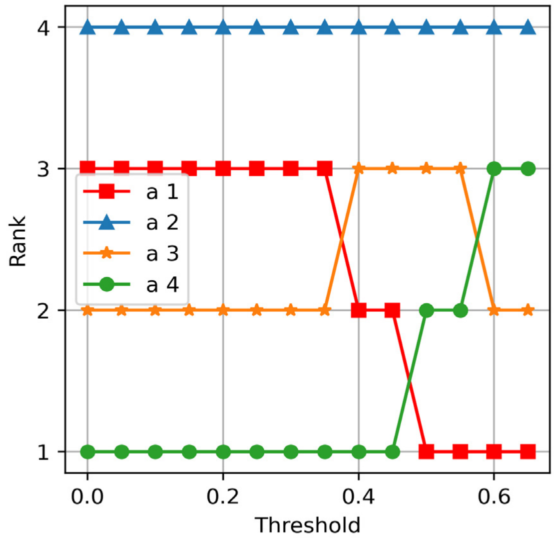

Figure 2. Changes in the rank of alternatives

Figure 2 illustrates the changes in the rank of alternatives for various thresholds. It is noteworthy that the order of alternatives is not changed after the selected threshold $T = 0.6$. This emphasizes the process of the proposed algorithm. In this regard, as soon as the collective majority consensus grade (∂) value becomes more significant than the threshold, the cycle of repeating the algorithm is stopped. The last ranking obtained for the alternatives is considered the optimal order. Another significant aspect is related to the favorable circumstances of the first alternative. According to the case study presented in this paper, the first site must be selected as the best alternative due to its ideal conditions. The ranking conditions for the second alternative are also significant since in all repetitions, it has been assigned the worst position without any change. The availability of a recursive loop in the autocratic algorithm makes it feasible to examine the impact of variable modifications on the final result.

7. Conclusion

In general, decision-making problems involve ambiguous, imprecise, and vague information. Neutrosophic sets can represent this kind of information more accurately and efficiently. This research proposed an autocratic strategy for dealing with multi-attribute group decision-making problems using single-valued neutrosophic sets. The transformation of multiple management decisions and weight matrices into a uniform aggregated assessment matrix is the core aspect of the proposed decision-making strategy. Using this strategy, the evaluated values of each attribute compared to the related decision-maker-provided option is indicated by a SVNN. Concerning technical applications and genuine scientific endeavors, neutrosophic sets may provide an extra tool for dealing with issues involving ambiguous, imprecise, and vague information. The proposed approach recalculates the weights of the decision-makers till their group consensus degree (GCD) is greater than or equal to a specified threshold value. This method is utilized for prioritizing recreation areas in a tourist industry, where the evaluated values of the attributes for alternatives and the weights of the selected features are represented by decision-makers based on single-valued neutrosophic sets. The proposed method uses comparisons of tourist sites based on the identified characteristics. Given the advantage of the autocratic strategy in decision-making with a few decision-makers, this approach features an exemplary performance in solving corporate and organizational issues where the decision-makers are represented by a limited number of experts. Future research may focus on creating a hybrid decision-making method that would take advantage of various techniques, while using an alternative mechanism simultaneously.

Acknowledgments

The author would like to thank the editor and anonymous reviewers for their insightful comments and suggestions.

REFERENCES

Atanassov, K. T. (1986) Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*. 20(1), 87-96.

Atanassov, K. T. (1999) *Intuitionistic Fuzzy Sets: Theory and Applications*. Berlin, Heidelberg, Physica-Verlag.

Alzahrani, F. A., Ghorui, N., Gazi, K. H., Giri, B. C., Ghosh, A. & Mondal, S. P. (2023) Optimal Site Selection for Women University Using Neutrosophic Multi-Criteria Decision Making Approach. *Buildings*. 13(1),152. doi: 10.3390/buildings13010152.

Ardil, C. (2021) Neutrosophic Multiple Criteria Decision Making Analysis Method for Selecting Stealth Fighter Aircraft. *International Journal of Aerospace and Mechanical Engineering*. 15(10), 466-470.

Balin, A. (2020) A novel fuzzy multi-criteria decision-making methodology based upon the spherical fuzzy sets with a real case study. *Iranian Journal of Fuzzy Systems*. 17(4), 167-177. doi: 10.22111/IJFS.2020.5413.

Debnath, S. (2022) Fuzzy Quadripartitioned Neutrosophic Soft Matrix Theory and Its Decision-Making Approach. *Journal of Computational and Cognitive Engineering*. 1(2), 88-93. doi: 10.47852/bonviewJCCE19522514205514.

Farid, H. M. A., Garg, H., Riaz, M. & Santos-García, G. (2022) Multi-criteria group decision-making algorithm based on single-valued neutrosophic Einstein prioritized aggregation operators and its applications. To be published in *Management Decision*. [Preprint]. doi: 10.1108/MD-04-2022-0484.

Kahraman, C., Çebi, S., Onar, S. & Öztayşi, B. (2022) Recent Developments on Fuzzy AHP & ANP Under Vague and Imprecise Data: Evidence from INFUS Conferences. *International Journal of the Analytic Hierarchy Process*. 14(2), 1-17. doi: 10.13033/ijahp.v14i2.1033.

Krishnan, E., Mohammed, R., Alnoor, A., Albahri, O. S., Zaidan, A. A., Alsattar, H., Albahri, A. S., Zaidan, B. B., Kou, G., Hamid, R. A., Alamoodi, A. H., & Alazab, M. (2021) Interval type 2 trapezoidal-fuzzy weighted with zero inconsistency combined with VIKOR for evaluating smart e-tourism applications. *International Journal of Intelligent Systems*. 36(6), 4723-4774. doi: 10.1002/int.22489.

Mu, Z., Zeng, S. & Wang, P. (2021) Novel approach to multi-attribute group decision-making based on interval-valued Pythagorean fuzzy power Maclaurin symmetric mean operator. *Computers & Industrial Engineering*. 155, 107049. doi: 10.1016/j.cie.2020.107049.

Mahmood, T. & Ali, Z. (2022) Prioritized Muirhead Mean Aggregation Operators under the Complex Single-Valued Neutrosophic Settings and Their Application in Multi-Attribute Decision-Making. *Journal of Computational and Cognitive Engineering*. 1(2), 56-73. doi: 10.47852/bonviewJCCE2022010104.

Mukherjee, A., Kundu, P. K. & Das, A. (2022) Transmission line fault classification under high noise in signal: a direct PCA-threshold-based approach. *Journal of The Institution of Engineers* (India). Series B, 103(1), 197-211. doi: 10.1007/s40031-021-00601-w.

Nafei, A. H., Yuan, W. & Nasseri, H. (2019) Group multi-attribute decision making based on interval neutrosophic sets. *Studies in Informatics and Control*. 228(3), 309-316. doi: 10.24846/v28i3y201907.

Nafei, A., Gu, Y. & Yuan, W. (2021) An extension of the TOPSIS for multi-attribute group decision making under neutrosophic environment. *Miskolc Mathematical Notes*. 22(1),393-405. doi: 10.18514/MMN.2021.3332.

Nafei, A., Javadpour, A., Nasseri, H. & Yuan, W. (2021) Optimized score function and its application in group multiattribute decision making based on fuzzy neutrosophic sets. *International Journal of Intelligent Systems*. 36(12), 7522-7543. doi: 10.1002/int.22597.

Nancy & Garg, H. (2016) An improved score function for ranking neutrosophic sets and its application to decision-making process. *International Journal for Uncertainty Quantification*. 6(5), 377-385.

Pramanik, S. & Mallick, R. (2019) TODIM strategy for multi-attribute group decision making in trapezoidal neutrosophic number environment. *Complex & Intelligent Systems*. 5(4), 379-389. doi: 10.1007/s40747-019-0110-7.

Rădulescu, C. Z. & Rădulescu, I. C. (2017) An extended TOPSIS approach for ranking cloud service providers. *Studies in Informatics and Control*. 26(2),183-192. doi: 10.24846/v26i2y201706.

Shahzadi, S., Rasool, A. & Santos-Garcıa, G. (2023) Methods to find strength of job competition among candidates under single-valued neutrosophic soft model. *Mathematical Biosciences and Engineering*. 20(3), 4609-4642. doi: 10.3934/mbe.2023214.

Smarandache, F. (1998) *A Unifying Field in Logics: Neutrosophic Logic. Neutrosophy, Neutrosophic Set, Neutrosophic Probability and Statistics*. Rehoboth, American Research Press. doi: 10.24846/v26i2y201706.

Smarandache, F. (2004) A geometric interpretation of the neutrosophic set-A generalization of the intuitionistic fuzzy set. In: *2011 IEEE International Conference on Granular Computing, 8-10 November 2011, Kaohsiung, Taiwan.* NY, IEEE. pp. 602-606. doi: 10.1109/GRC.2011.6122665.

Smarandache, F. (2005) Neutrosophic set - a generalization of the intuitionistic fuzzy set. *International Journal of Pure and Applied Mathematics*. 24(3), 287-297.

Smarandache, F. (2020) The score, accuracy, and certainty functions determine a total order on the set of neutrosophic triplets (T, I, F). *Neutrosophic Sets and Systems*. 38(1), 1-14.

Şahin, R. (2014) *Multi-criteria neutrosophic decision making method based on score and accuracy functions under neutrosophic environment*. [Preprint]. https://arxiv.org/abs/1412.5202.

Wang, H., Smarandache, F., Zhang, Y. & Sunderraman, R. (2010) *Single valued neutrosophic sets. Multispace & Multistructure. Neutrosophic Transdisciplinarity*. Hanko, North-European Scientific Publishers Hanko.

Zadeh, L. A. (1965) Fuzzy sets. *Information and Control*. 8(3), 338-353.