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A Novel Extension of the TOPSIS Method Adapted for the Use of Single-Valued Neutrosophic Sets and Hamming Distance for E-Commerce Development Strategies Selection

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Abstract: Neutrosophic sets have been recognized as an effective approach in solving complex decision-making (DM) problems, mainly when such problems are related to uncertainties, as published in numerous articles thus far. The use of the three membership functions that can be used to express accuracy, inaccuracy, and indeterminacy during the evaluation of alternatives in multiple-criteria DM can be said to be a significant advantage of these sets. By utilizing these membership functions, neutrosophic sets provide an efficient and flexible approach to the evaluation of alternatives, even if DM problems are related to uncertainty and predictions. On the other hand, the TOPSIS method is a prominent multiple-criteria decision-making method used so far to solve numerous decision-making problems, and many extensions of the TOPSIS method are proposed to enable the use of different types of fuzzy as well as neutrosophic sets. Therefore, a novel extension of the TOPSIS method adapted for the use of single-valued neutrosophic sets was considered in this paper.

Keywords: multiple-criteria decision-making; neutrosophic; single-valued neutrosophic sets; TOPSIS; Hamming distance; Euclidean distance; e-commerce development strategies

1. Introduction

As one of the essential elements of the modern world economy and the increasing use of advanced information and communication technology (ICT), technological changes have driven fundamental changes in the economic and social environments, thereby transforming society from the industrial into the information age [1]. The increasing use of ICT has significantly changed the way we live, learn, and work, transforming the direction of the interaction of people, business systems, and public institutions. The development of information technologies, and in particular, the advancement of

Internet technologies, enables existing businesses to progress and the opening of new businesses, leading to the growth of e-business and the digital economy [2,3].

The Internet has contributed to the extremely dynamic development of e-commerce within e-business. In its simplest sense, e-commerce implies the purchase and sale of goods or services online as well as advertising revenue. Without the Internet, e-commerce would be virtually non-existent. Therefore, e-commerce includes all activities of buying and selling products and services that are performed via the Internet or other electronic communication channels [4]. First of all, e-commerce consists of distributing, buying, selling, marketing, and servicing products and services through the Internet. It also incorporates electronic money transfer, supply chain management, e-marketing, electronic data exchange, and automated data collection systems [5]. Over time, e-commerce has transformed from a mechanism for online retail sales into something much broader [6]. This is why it is of great importance which e-commerce strategy the company will choose to implement [7]. The selection of an optimal strategy is vital because the strategy defines the future direction and actions of the organization or part of the organization [8]. Developing an e-commerce strategy requires combining existing approaches to business and developing an information systems strategy. In order to achieve a competitive advantage, it is crucial to join innovative techniques in traditional strategic approaches [9]. The implementation of an adequate strategy may help the company to achieve and maintain its competitive advantage in the long run [10].

Many of the real problems are often characterized by a number of mostly antagonistic criteria. Multiple-criteria decision-making (MCDM) is a notable part of operational research. It considers the issues in which we are faced with a greater number of, most often conflicting, criteria when making a decision [11–13]. The extraordinarily rapid and dynamic development of MCDM worldwide has contributed to a number of MCDM methods and techniques proposed by scholars to solve a wide variety of problems [14,15]. Some of the prominent methods that are most applied are the AHP method (Analytic hierarchy process) [16], the ELECTRE method (Elimination et choix traduisant la réalité) [17], the PROMETHEE method (Preference ranking organization method for enrichment evaluations) [18], the TOPSIS method (Technique for order preference by similarity to ideal solution) [19], the COPRAS method (Complex proportional assessment of alternatives) [20], the VIKOR method (Visekriterijumska optimizacija i kompromisno resenje) [21], the MOORA method (Multi-objective optimization on basis of ratio analysis) [22], the MULTIMOORA method (Multi-objective optimization by ratio analysis plus the full multiplicative form) [23], and so on.

Hwang and Yoon [19] develop the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution). To solve a broader range of problems when problems are related to uncertainties, ambiguities, and vagueness, the TOPSIS method has a proper extension based on the application of fuzzy, intuitionistic, grey, and neutrosophic numbers to be able to cope with these problems. To date, the TOPSIS method has been applied to solving many cases, often in combination with other techniques, some of which are as follows: the application of TOPSIS when deciding on a discipline, course, and university [24]; the application of entropy TOPSIS-F for the performance assessment of green suppliers [25]; the evaluation of solar power technologies based on the application of the intuitionistic fuzzy TOPSIS [26]; hotel evaluation and selection based on the modified TOPSIS decision support algorithm [27]; the evaluation of the sustainable energy planning strategies based on the SWOT-AHP method and Fuzzy TOPSIS method [28]; supplier evaluation and selection based on the green innovation ability based on the BWM and fuzzy TOPSIS [29]; website assessment by employing the interval type-2 fuzzy number TOPSIS approach [30]; assessment in civil engineering [31–33]; evaluation and selection of personnel [34–37]; and so on.

Neutrosophic sets were established by Smarandache [38] to deal with complex DM problems related to uncertainties, which are followed by inconsistent and indeterminate information. The use of the three membership functions in order to express accuracy, indeterminacy, and inaccuracy during the evaluation of alternatives in MCDM can be said to be a very important and significant advantage of neutrosophic sets. So far, neutrosophic sets have been utilized in different fields such as medical

analysis [39–42], transport [43,44], information and communication technology [45–47], MCDM [48–52], and so forth.

Therefore, a novel extension of the TOPSIS method adapted for the application of single-valued neutrosophic sets is the subject matter of consideration in this manuscript. The applicability and usability of the developed single-valued neutrosophic TOPSIS extension are demonstrated on a numerical illustration of the evaluation and selection of e-commerce development strategies. For all of the preceding reasons, the remainder of the manuscript is based on the following global organization of sections. The preliminaries are presented in Section 2; in Section 3, the TOPSIS method customized to the use of single-valued neutrosophic numbers (SVNNs) and group decision-making is presented; Section 4 contains a presentation of the numerical clarification, whereas Section 5 presents a discussion and a comparison analysis. Finally, concluding remarks are specified at the end of the manuscript.

2. Preliminaries

In this part of the manuscript, some fundamental definitions and notations of neutrosophic sets (NS), single-valued neutrosophic set (SVNS), and single-valued neutrosophic numbers (SVNN) are given.

Definition 1. [53] Let X denote the universe of discourse. The NS A in X has the following form

$$A = \{ \langle x, \mu_A(x), \pi_A(x), \nu_A(x) \rangle \mid x \in X \}, \quad (1)$$

where $\mu_A(x)$ denotes the truth-membership function; $\mu_A \in]^{-0}, 1^+[$; $\pi_A(x)$ denotes the falsity-membership function; $\pi_A \in]^{-0}, 1^+[$; and $\nu_A(x)$ denotes the falsity-membership function, $\nu_A \in]^{-0}, 1^+[$.

These membership functions must satisfy the following constraint $^{-0} \leq \mu_A(x) + \pi_A(x) + \nu_A(x) \leq 3^+$.

Definition 2. [54] Let X be a nonempty set. The SVNS A in X has the following form

$$A = \{ \langle x, \mu_A(x), \pi_A(x), \nu_A(x) \rangle \mid x \in X \} \quad (2)$$

where membership functions $T_A, I_A,$ and $F_A \in]^{-0}, 1^+[$ and satisfy the following constraint $0 \leq \mu_A(x) + \pi_A(x) + \nu_A(x) \leq 3$.

Definition 3. [54] A SVNN $a = \langle t_a, i_a, f_a \rangle$ is a special case of a SVNS on the set of real numbers \mathfrak{R} , where $t_a, i_a, f_a \in [0, 1]$ and $0 \leq t_a + i_a + f_a \leq 3$.

Definition 4. [53] Let $x_1 = \langle t_1, i_1, f_1 \rangle$ be a SVNN and $\lambda > 0$. The multiplication SVNNs and λ are as follows:

$$\lambda x_1 = \langle 1 - (1 - t_1)^\lambda, i_1^\lambda, f_1^\lambda \rangle \quad (3)$$

Definition 5. Let $X = (x_1, x_2, \dots, x_n)$ and $Y = (y_1, y_2, \dots, y_n)$ be two n -dimensional vectors, $x_i = \langle t_{xi}, i_{xi}, f_{xi} \rangle$ and $y_i = \langle t_{yi}, i_{yi}, f_{yi} \rangle$. The Hamming distance between X and Y is defined as

$$h_{(X,Y)} = \frac{1}{3n} \sum_{i=1}^n (|t_{xi} - t_{yi}| + |i_{xi} - i_{yi}| + |f_{xi} - f_{yi}|). \quad (4)$$

Definition 6. Let $X = (x_1, x_2, \dots, x_n)$ and $Y = (y_1, y_2, \dots, y_n)$ be two n -dimensional vectors, $x_i = \langle t_{xi}, i_{xi}, f_{xi} \rangle$ and $y_i = \langle t_{yi}, i_{yi}, f_{yi} \rangle$. The Euclidean distance between X and Y is defined as

$$e_{(X,Y)} = \frac{1}{3n} \sqrt{\sum_{i=1}^n ((t_{xi} - t_{yi})^2 + (i_{xi} - i_{yi})^2 + (f_{xi} - f_{yi})^2)}. \quad (5)$$

Definition 7. [55] Let $x = \langle t, i, f \rangle$ be a SVN. The score function s of x is defined as

$$s = (1 + t - 2i - f)/2, \quad (6)$$

where $s \in [-1, 1]$.

Definition 8. [56] Let $x = \langle t, i, f \rangle$ be a SVN. The cosine similarity measure of x is the expression

$$c = \frac{t}{\sqrt{t^2 + i^2 + f^2}} \quad (7)$$

Definition 9. [55] Let $a_j = \langle t_j, i_j, f_j \rangle$ be a collection of SVNs and $W = (w_1, w_2, \dots, w_n)^T$ be an associated weighting vector. The Single-Valued Neutrosophic Weighted Average (SVNWA) operator of a_j is

$$SVNWA(a_1, a_2, \dots, a_n) = \sum_{j=1}^n w_j a_j = \left(1 - \prod_{j=1}^n (1 - t_j)^{w_j}, \prod_{j=1}^n (i_j)^{w_j}, \prod_{j=1}^n (f_j)^{w_j} \right), \quad (8)$$

where w_j is the element j of the weighting vector, $w_j \in [0, 1]$ and $\sum_{j=1}^n w_j = 1$.

3. The TOPSIS Method Customized to the Use of SVNs and Group Decision-Making

3.1. The TOPSIS Method

The TOPSIS method, originated by Hwang and Yoon [19], is a very prominent and frequently used MCDM method. Compared to other MCDM methods, this method has a characteristic approach to determine the most acceptable alternative and is based upon the concept that an alternative is defined on the basis of the shortest distance to the ideal solution and the longest distance to the anti-ideal solution. The relative distance C_i of the i th alternative to the ideal and anti-ideal solutions is calculated as

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad (9)$$

where d_i^+ and d_i^- denote the distance of the alternative i from the ideal and anti-ideal solutions, respectively, and $C_i \in [0, 1]$.

The distance of each alternative from the ideal and anti-ideal solutions are computed as follows:

$$d_i^+ = \left\{ \sum_{j=1}^n (w_j (r_{ij} - r_j^+))^2 \right\}^{0.5} \quad (10)$$

and

$$d_i^- = \left\{ \sum_{j=1}^n (w_j (r_{ij} - r_j^-))^2 \right\}^{0.5}. \quad (11)$$

In Equations (10) and (11), w_j denotes the weight of the criterion j ; r_j^+ and r_j^- denote the coordinate j of the ideal and anti-ideal solutions, respectively; and r_{ij} is the normalized rating of the alternative i to the criterion j .

The ordinary TOPSIS method utilizes the Euclidean distance to determine the separation measures. However, some authors such as Chang et al. [57], Shanian and Savadogo [58], and Hwang and Yoon [19], have also considered the application of the Hamming distance for that purpose:

$$d_i^+ = \sum_{j=1}^n w_j |r_{ij} - r_i^+|, \text{ and} \quad (12)$$

$$d_i^- = \sum_{j=1}^n w_j |r_{ij} - r_i^-|. \quad (13)$$

In the numerous extensions of the TOPSIS method that were later proposed, the application of the Hamming distance has become more common such as in the research of Gautam and Singh [59], Izadikhah [60], and Chen and Tsao [61].

The ordinary TOPSIS method uses the vector normalization procedure for the calculation of normalized ratings, as

$$r_{ij} = \frac{x_{ij}}{\left(\sum_{i=1}^n x_{ij}^2\right)^{1/2}} \quad (14)$$

where r_{ij} is the normalized rating of the alternative i to the criterion j , and x_{ij} is the rating of the alternative i to the criterion j .

In some extensions of the TOPSIS method, however, this normalization procedure is followed with a simpler normalization procedure [31,62], as follows:

$$r_{ij} = \frac{x_{ij}}{x_j^+}. \quad (15)$$

In Equation (15), it is assumed that x_j^+ denotes the largest rating of the criterion j .

The ideal A^* and the anti-ideal A^- solutions are defined by

$$A^+ = \left\{ r_1^+, r_2^+, \dots, r_n^+ \right\} = \left\{ \max_i r_{ij} | j \in \Theta_{\max}, (\min_i r_{ij} | j \in \Theta_{\min}) \right\}, \quad (16)$$

$$A^- = \left\{ r_1^-, r_2^-, \dots, r_n^- \right\} = \left\{ \min_i r_{ij} | j \in \Theta_{\max}, (\max_i r_{ij} | j \in \Theta_{\min}) \right\}, \quad (17)$$

where r_j^+ denotes the coordinate j of the ideal solution; r_j^- denotes the coordinate j of the anti-ideal solution; and Θ_{\max} and Θ_{\min} denote the sets of beneficial and non-beneficial criteria, respectively.

3.2. An Extension of the TOPSIS Method Adapted for the Use of SVNNs

The typical MCDM problem that includes m alternatives and n criteria can concisely be presented in the following matrix form:

$$D = [x_{ij}]_{m \times n}, \quad (18)$$

$$W = [w_j]_n. \quad (19)$$

The entry x_{ij} in the evaluation matrix D means the rating of the alternative i with respect to the criterion j and entries w_j in W of the weight vector denote the weights of the criterion j , for each $i = 1, \dots, m$ and $j = 1, \dots, n$.

However, many practical DM problems require the participation of more decision-makers or experts in the evaluation process. Therefore, in multiple-criteria group decision-making (MCGDM), there is more than one decision-making matrix

$$D^k = [x_{ij}^k]_{m \times n}, k = 1, \dots, K, \quad (20)$$

where D^k denotes an evaluation matrix formed by the decision-maker and/or expert k ; x_{ij}^k is the rating of the alternative i with respect to the criterion j obtained from the decision-maker and/or expert k ; and K denotes the number of decision-makers and/or experts.

In the MCGDM process, decision-makers and/or experts often have different experiences and/or specific knowledge of the problem that has to be solved, which is why another weighting vector can be used to express the impact of the decision-makers and/or experts on the final evaluation, namely as follows:

$$[\omega_k]_K. \quad (21)$$

The value ω_k is the significance or impact of the decision-maker and/or expert k on the overall evaluation.

Using the weighting vector that expresses the impact of decision-makers on the overall evaluation, the individual evaluation matrix obtained from the decision-makers and/or experts, and a sort of aggregation operator, an overall group decision-making matrix can be constructed.

Taking into consideration the foregoing facts pertaining to the MCGDM, the specifics of SVNNs and operations over them as well as the previously proposed extension of the TOPSIS method [54,63,64], a thorough step-by-step procedure of the adapted TOPSIS method, as shown in Figure 1, can be accurately presented through the following basic steps:

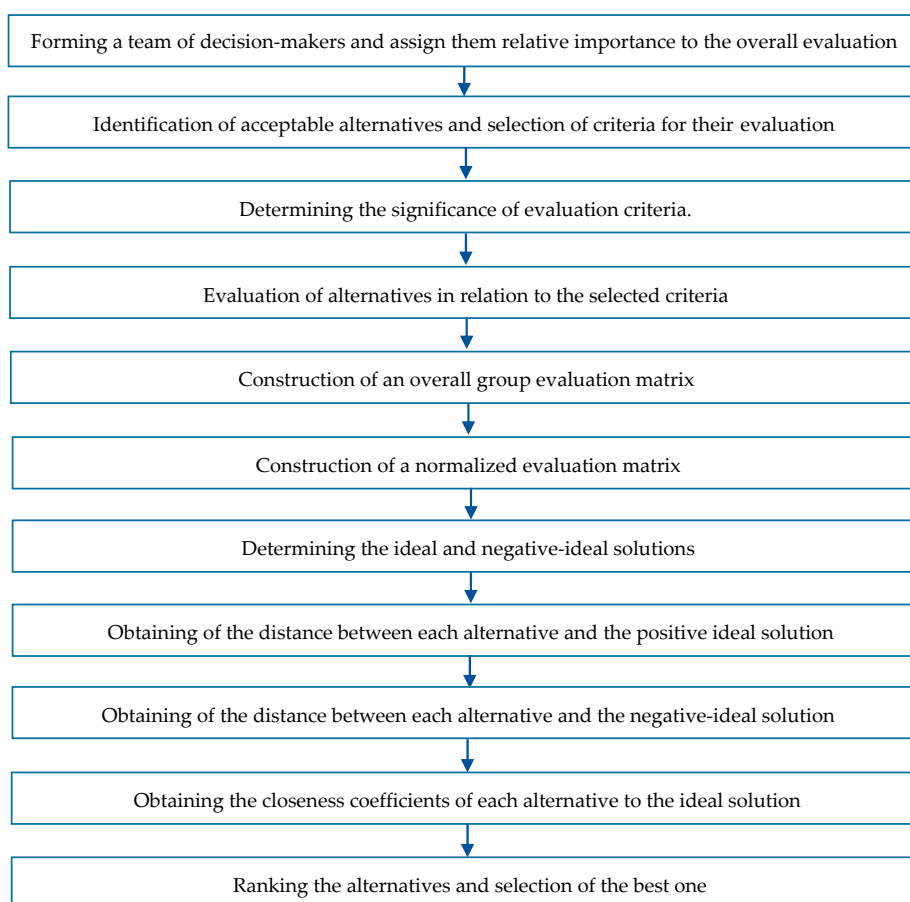


Figure 1. Computational procedure of the adapted TOPSIS method.

Step 1. Forming a team of decision-makers and assigning them relative importance to the overall evaluation. In the first step, a team of decision-makers and/or experts is formed and relative importance is assigned to each of them, if necessary. In many cases, all decision-makers and/or experts have equal importance to the final evaluation.

Step 2. Identification of acceptable alternatives and selection of criteria for their evaluation. In the second step, the team of decision-makers identified the feasible alternatives and determined a set of evaluation criteria.

Step 3. Determining the significance of evaluation criteria. In this step, the team of decision-makers and/or experts determined the weights of the evaluation criteria. A number of methods that can be used to determine criteria weights have been considered in many papers published in scientific and professional journals [16,65–68].

Step 4. Evaluation of alternatives in relation to the selected criteria. In the fourth step, each decision-maker performs an evaluation and forms their own evaluation matrix, in which the ratings are expressed by using SVNNS. As a result of performing this step, a K evaluation matrix is formed as follows:

$$D^k = [x_{ij}^k]_{m \times n} = [\langle t_{ij}^k, i_{ij}^k, f_{ij}^k \rangle]_{m \times n}, \quad (22)$$

where $\langle t_{ij}^k, i_{ij}^k, f_{ij}^k \rangle$ denotes the rating of the alternative i with respect to the criterion j , obtained from the decision-maker expert k .

Step 5. Construction of an overall group evaluation matrix. In this step, the individual attitudes of the decision-makers involved in the evaluation are transformed into one overall group evaluation matrix by using a SVNWA operator (i.e., by applying Equation (8)). As a result of performing this step, a matrix of the following form is formed:

$$D = [x_{ij}]_{m \times n} = [\langle t_{ij}, i_{ij}, f_{ij} \rangle]_{m \times n}, \quad (23)$$

where $\langle t_{ij}, i_{ij}, f_{ij} \rangle$ denotes the rating of the alternative i in relation to the criterion j .

Step 6. Construction of a normalized evaluation matrix. The normalization of the overall group evaluation matrix can be performed by applying Equation (3) and the following λ :

$$\lambda = \frac{1}{\max(\max_i t_{ij}, \max_i i_{ij}, \max_i f_{ij})}. \quad (24)$$

This step is not necessary if all ratings belong to the interval $[0, 1]$.

Step 7. Determining the ideal and negative-ideal solutions. In the case when all evaluation criteria are beneficial, the ideal and negative ideal solutions are calculated as follows:

$$A^+ = \{r_1^+, r_2^+, \dots, r_n^+\} = \{\langle \max_i t_{ij}, \min_i i_{ij}, \min_i f_{ij} \rangle\}, \quad (25)$$

$$A^- = \{r_1^-, r_2^-, \dots, r_n^-\} = \{\langle \min_i t_{ij}, \max_i i_{ij}, \max_i f_{ij} \rangle\}. \quad (26)$$

Step 8. Obtaining the distance between each alternative and the positive ideal solution. The distances between the alternatives and the positive ideal solution can be determined by applying Equations (4) or (5).

Step 9. Obtaining the distance between each alternative and the negative-ideal solution. The distances between the alternatives and the negative ideal solution can be determined in a similar manner as the distances to the ideal solution.

Step 10. Obtaining the closeness coefficients of each alternative to the ideal solution. Applying Equations (4) and (5), SVNNS are transformed into the resulting crisp values, thus allowing the application of Equation (9) to determine the closeness coefficients to the ideal solution, as in the ordinary TOPSIS method.

Step 11. Ranking the alternatives and selection of the best one. The final ranking of the considered alternatives remains the same as in the ordinary TOPSIS method, which means that an alternative with a higher value of the closeness coefficient is more preferable.

4. A Numerical Illustration

To demonstrate the efficiency and the applicability of the proposed extension, an example of the evaluation of e-commerce strategies adopted from Stanujkić et al. [69] is the subject matter of consideration in this section of the paper. Suppose a team of three decision-makers should evaluate three e-commerce development strategies based on five criteria. The e-commerce development strategies (ECDS) and the evaluation criteria are shown in Tables 1 and 2.

Table 1. E-commerce development strategies.

Alternatives	Designation
A_1 —E-customization and personalization—Ansari & Mela [70]	ECDS1
A_2 —Social E-commerce adoption model—Hajli [71]	ECDS2
A_3 —Strong search engine optimization (SEO)—Sen [72]	ECDS3

Table 2. E-commerce development strategy evaluation criteria.

Criteria	Designation
C_1 —Feasibility of the strategy	FS
C_2 —Implementation speed	IS
C_3 —Compliance with the corporate strategy	CS
C_4 —Compliance of the strategy with the mission and vision of the company	MV
C_5 —General acceptance	GA

The ratings obtained from the three decision-makers for the proposed strategies are shown in Tables 3–5.

Table 3. The ratings received from the first decision-maker.

	FS	IS	CS	MV	GA
ECDS1	<0.6, 0.1, 0.1>	<0.6, 0.1, 0.1>	<0.6, 0.1, 0.1>	<0.4, 0.1, 0.1>	<0.4, 0.1, 0.1>
ECDS2	<1.0, 0.0, 0.0>	<0.8, 0.0, 0.0>	<1.0, 0.1, 0.1>	<1.0, 0.1, 0.3>	<1.0, 0.0, 0.1>
ECDS3	<0.6, 0.0, 0.2>	<0.6, 0.2, 0.1>	<0.8, 0.2, 0.1>	<1.0, 0.2, 0.3>	<1.0, 0.0, 0.2>

Table 4. The ratings received from the second decision-maker.

	FS	IS	CS	MV	GA
ECDS1	<0.5, 0.0, 0.1>	<0.7, 0.1, 0.1>	<0.5, 0.0, 0.1>	<0.4, 0.1, 0.1>	<0.4, 0.0, 0.1>
ECDS2	<0.9, 0.0, 0.0>	<0.7, 0.1, 0.0>	<0.9, 0.0, 0.0>	<1.0, 0.0, 0.1>	<0.7, 0.0, 0.2>
ECDS3	<0.7, 0.0, 0.0>	<0.6, 0.1, 0.1>	<0.8, 0.1, 0.2>	<0.9, 0.1, 0.3>	<0.8, 0.0, 0.2>

Table 5. The ratings received from the third decision-maker.

	FS	IS	CS	MV	GA
ECDS1	<0.5, 0.0, 0.0>	<0.8, 0.1, 0.1>	<0.6, 0.0, 0.1>	<0.5, 0.0, 0.0>	<0.5, 0.1, 0.1>
ECDS2	<0.8, 0.0, 0.1>	<0.7, 0.0, 0.0>	<1.0, 0.0, 0.0>	<0.9, 0.0, 0.1>	<0.6, 0.0, 0.1>
ECDS3	<0.8, 0.1, 0.1>	<0.7, 0.0, 0.0>	<0.8, 0.0, 0.1>	<0.9, 0.1, 0.2>	<0.8, 0.0, 0.0>

After that, a group evaluation matrix was determined by using Equation (6), whereby all the decision-makers had the same importance $\omega_1 = \omega_2 = \omega_3 = 0.33$. The group evaluation matrix is presented in Table 6.

Table 6. The group evaluation matrix.

	FS	IS	CS	MV	GA
ECDS1	<0.5, 0.0, 0.0>	<0.7, 0.1, 0.1>	<0.6, 0.0, 0.1>	<0.4, 0.0, 0.0>	<0.4, 0.0, 0.1>
ECDS2	<1.0, 0.0, 0.0>	<0.7, 0.0, 0.0>	<1.0, 0.0, 0.0>	<1.0, 0.0, 0.1>	<1.0, 0.0, 0.1>
ECDS3	<0.7, 0.0, 0.0>	<0.6, 0.0, 0.0>	<0.8, 0.0, 0.1>	<1.0, 0.1, 0.3>	<1.0, 0.0, 0.0>

In the following step, the ideal and negative ideal solutions shown in Table 7 are determined by applying Equations (23) and (24).

Table 7. The ideal and negative ideal solutions.

	FS	IS	CS	MV	GA
ECDS ⁺	<1.0, 0.0, 0.0>	<0.7, 0.0, 0.0>	<1.0, 0.0, 0.0>	<1.0, 0.0, 0.0>	<1.0, 0.0, 0.0>
ECDS ⁻	<0.5, 0.0, 0.0>	<0.6, 0.1, 0.1>	<0.6, 0.0, 0.1>	<0.4, 0.1, 0.3>	<0.4, 0.0, 0.1>

The calculation details obtained by applying the TOPSIS method and the two distance measures are presented in Tables 8 and 9.

Table 8. The computational details obtained by using the Hamming distance.

	d_i^+	d_i^-	C_i	Rank
ECDS1	0.87	0.69	0.44	3
ECDS2	0.38	1.08	0.74	1
ECDS3	0.63	0.66	0.51	2

Table 9. The computational details obtained by using the Euclidean distance.

	d_i^+	d_i^-	C_i	Rank
ECDS1	3.38	3.24	0.490	3
ECDS2	1.70	4.25	0.714	1
ECDS3	2.60	2.54	0.495	2

The calculation details obtained by utilizing the TOPSIS method and the Hamming distance are presented in Table 8. In this case, all the criteria had the same importance of $w_j = 0.20$.

As can be observed from Table 8, the most acceptable alternative (i.e., e-commerce development strategy) is designated as ECDS2, which means that the most appropriate e-commerce development strategy is the “social e-commerce adoption” alternative.

5. Discussion and Comparison Analysis

In order to confirm the obtained results, similar calculations were performed by applying the TOPSIS method with the Euclidean distance, and the two commonly used approaches in the case of applying neutrosophic sets (i.e., the score function and the cosine similarity measure).

The calculation details obtained by using the TOPSIS method and the Euclidean distance are presented in Table 9. As can be observed from Table 9, the application of the TOPSIS method with the Euclidean distance produced the same ranking results.

To check the stability of the obtained ranking order of the alternatives, the calculation was repeated five times with the weighting vectors shown in Table 10.

Table 10. The weighting vectors used for the recalculation.

	w_1	w_2	w_3	w_4	w_5	Σw_j
W_1	0.40	0.15	0.15	0.15	0.15	1.00
W_2	0.15	0.40	0.15	0.15	0.15	1.00
W_3	0.15	0.15	0.40	0.15	0.15	1.00
W_4	0.15	0.15	0.15	0.40	0.15	1.00
W_5	0.15	0.15	0.15	0.15	0.40	1.00

The ranking results obtained by using the five different weighting vectors and the two distances are given in Tables 11 and 12.

Table 11. The ranking results obtained by using the Hamming distance and different W_i .

	W_1		W_2		W_3		W_4		W_5	
	C_i	Rank	C_i	Rank	C_i	Rank	C_i	Rank	C_i	Rank
ECDS1	0.45	3	0.51	2	0.44	3	0.39	3	0.43	3
ECDS2	0.74	1	0.70	1	0.72	1	0.75	1	0.78	1
ECDS3	0.50	2	0.43	3	0.54	2	0.59	2	0.49	2

Table 12. The ranking results obtained by using the Euclidean distance and different W_i .

	W_1		W_2		W_3		W_4		W_5	
	C_i	Rank	C_i	Rank	C_i	Rank	C_i	Rank	C_i	Rank
ECDS1	0.49	3	0.56	2	0.48	3	0.44	3	0.48	2
ECDS2	0.72	1	0.67	1	0.70	1	0.73	1	0.76	1
ECDS3	0.50	2	0.41	3	0.54	2	0.57	2	0.46	3

The use of different weighting vectors caused changes in the ranking order in two cases, namely: W_2 and W_5 . In the first case (W_2), both distances gave the same ranking order, whereas in the second case (W_5), there was a difference in the second- and third-ranked alternatives.

Based on the foregoing, it can be concluded that the developed extension of the TOPSIS method can be employed with any of the two previously considered distances (i.e., with the one easier to calculate such as the Hamming distance, or the one slightly more complex to calculate in the case of using SVNNS like Euclidean distance).

To finally verify the ranking results obtained by the developed adaptation of the TOPSIS method, an additional ranking of the strategies was performed by using two commonly used approaches (i.e., the score function and the cosine similarity measure). The values of the score function and the cosine similarity measure for the considered alternatives were determined by applying Equations (6) and (7), respectively, to the overall ratings calculated by applying Equation (8). In this calculation, all the criteria again had the same importance of $w_j = 0.20$. The achieved ranking results are shown in Table 13.

Table 13. The ranking by using the score function and the cosine similarity measure.

	Overall Ratings	Score	Rank	Cosine	Rank
ECDS1	<0.55, 0.00, 0.00>	0.78	3	0.55	3
ECDS2	<1.00, 0.00, 0.00>	1.00	1	1.00	1
ECDS3	<1.00, 0.00, 0.00>	1.00	1	1.00	1

Table 13 allows us to note that the obtained results were partly different from the results shown in Tables 8 and 9. The difference occurs with the alternative ECDS3, which now shared first place with the alternative ECDS2, whereas the alternative ECDS1 ranked second when using the TOPSIS method.

Generally speaking, the alternative ECDS2 was the best-ranked when using all the approaches (as seen in Figure 2), although some deviations in the ranking orders obtained by using different approaches were expected. Possible deviations in the ranking orders obtained by using different approaches are caused by the differences and specificities of the calculation procedures applied in different approaches, whereas deviations usually reflect in the case of worse-ranked alternatives.

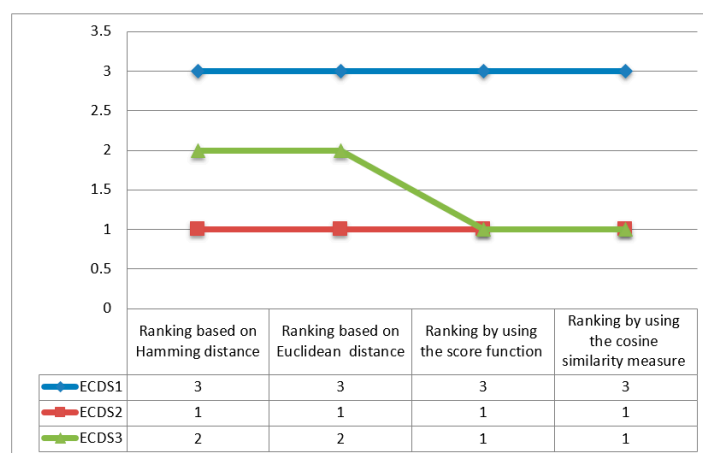


Figure 2. Ranking results achieved by utilizing different procedures.

6. Conclusions

As a generalization of fuzzy sets and their various extensions, neutrosophic sets introduce three membership functions, thus enabling an easier and more efficient evaluation of alternatives in the cases of solving problems associated with ambiguities and uncertainties. Therefore, several approaches have been proposed for ranking neutrosophic numbers, and numerous MCDM methods have been adapted for the purpose of their use.

The TOPSIS method is a prominent MCDM method that has been used so far to solve numerous decision-making problems, and many extensions of the TOPSIS method have been proposed to enable using different types of fuzzy as well as neutrosophic numbers. Based on a previously proposed extension, a new adaptation to use single-valued neutrosophic numbers is being considered. The additional goal of this study was to confirm the applicability of the Hamming distance alternatively to the Euclidean distance. The results of the considered numerical illustration and the conducted comparative analysis indicate the justified application of the Hamming distance with a less complex calculation procedure instead of the Euclidean distance with a much more complex calculation procedure, especially in the case of neutrosophic set application. Furthermore, the proposed approach has enabled the use of the Hamming distance and/or Euclidean distance.

Based on the conducted numerical illustration, the most acceptable alternative is ECDS2, the Social E-commerce adoption model. Furthermore, the reliability of the TOPSIS extension based on SVNNS was additionally verified by utilizing the score function and cosine similarity measure. It is noticeable that alternatives ECDS2 and ECDS3 had the same ranking result. Additionally, alternative ECDS2, the Social E-commerce adoption model, was the best-ranked when using different ranking approaches (ranking based on Hamming distance and Euclidean distance, and ranking based on score function and cosine similarity measure).

The proposed TOPSIS extension based on SVNNS proved to be efficient and easy to use when solving decision-making problems that are complex, multifaceted, and often associated with ambiguities and uncertainties. In addition, TOPSIS SVNNS is a good choice when it comes to the evaluation and selection of e-commerce development strategies.

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