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Multi-Aspect Decision-Making Process in Equity Investment Using Neutrosophic Soft Matrices

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Abstract: Neutrosophic theory alleviates the ambiguity situation more effectively than fuzzy sets. Neutrosophic soft set deals with the combination of truth, indeterminacy and falsity membership. This provides a space for the convention with multi-aspect decision-making (MADM) problems that involve these combinations. The main aim of this paper is to provide a unique ranking for the alternatives to overcome the existing drawbacks in the said environment. Initially, a new score function and the weighted neutrosophic vector are discussed. Secondly, to show the supremacy of the proposed score function a comparison analysis is discussed between the existing score method and the proposed approach. Thirdly, algorithm and flowchart are discussed for the case study. Lastly, a new technique for ranking the alternatives is discussed which enables us to determine the unique highest score. The working model is illustrated with suitable examples to authenticate the tool and to demonstrate the effectiveness of the planned approach.

Keywords: Single valued neutrosophic sets, Neutrosophic soft matrix (NSM), weighted neutrosophic vector, Score and value function, Multi-aspect decision-analysis.

1. Introduction

Our world is complex and rapid changes keep occurring in the field of engineering, medical science, banking, modern education, social, economic, and various other fields. Complexity generally arises from ambiguity and to overcome these situations in day to day life, Zadeh (1965) introduced a fuzzy set (FS) [14] and an interval-valued fuzzy set (IVFS) [15]. Atanassov (1986) proposed the concept of intuitionistic fuzzy set (IFS) [1] and interval-valued intuitionistic fuzzy set [2] a combination of membership and non-membership functions. However, both fuzzy and intuitionistic fuzzy sets cannot treat the indeterminacy part in the day to day problems. To deal with indeterminacy situations, Smarandache (1998) grounded the neutrosophic set (NS) [10] theory which is an overview of FS and IFS. In plithogenic set (PS) elements are characterized by the attribute values. It was introduced by Smarandache [27] as a generalization of crisp, fuzzy, intuitionistic fuzzy, and neutrosophic sets.

FS, IVFS, IFS, NS, PS and hybrid of these sets are used in various decision-making problems. Decision making plays a significant role in today's social, scientific and economic endeavor. Most of the decision-making process is based on an objective to reduce the cost, reduce the production time, and increase the profit for the organization. However, considering today's environment the decision should include various objective sources to deal with uncertainty. It weighs the provided information and chooses the best criteria for subsequent action. The information provided in a complex world is likely ambiguous, hence the outcomes are vague, irrespective of the decision made on the criteria chosen. To explain this scenario, consider the criteria of taking a loan from a bank. The outcome can be ambiguous with the possibility of a loan getting approved or declined or undetermined. The primary issues in MADM are to rank the relative importance of each of the objectives. Despite our vast knowledge and experience in handling these objectives, we come across violations in our everyday life. A bank manager makes a decision in this complex environment and figures out that his/her decision becomes weird. We have come across many situations where the loan applicant fails to repay the loan amount despite following the scrutiny process. The said problem could be due to the change in information and condition according to the situation. The outcomes of these situations have nothing to do with the quality of the decisions made. The best we can do with our knowledge is that in the long run the `good decisions' will outplay the `bad decisions'.

Most of the researchers utilize NS as a significant tool to analyze MADM problems with the help of aggregation operators, information measures, score functions and machine learning algorithms. Abhishek et al. [28] developed a parametric divergence measure and initiated the concept of pattern recognition and medical diagnosis problem for neutrosophic sets. Abdel-Basset et al. [18] proposed a hybrid combination between analytical hierarchical process and neutrosophic theory to solve the uncertainty involved in the technology of the internet of things. Abhisek and Rakesh [29] proposed a notion for finding the threshold value in decision-making problems when the qualitative and quantitative information is outsized. Abdel-Basset et al. [20] proposed the concept of type 2 neutrosophic number TOPSIS method to deal with real case decision problems. Edalatpanah and Smarandache [30] found a new method to solve the data envelopment analysis using the weighted arithmetic average operator in neutrosophic sets. Abdel-Basset et al. [19] initiated a neutrosophic approach for evaluating green supply chain management to aid managers and decision-makers. Vakkas et al. [33] proposed a novel ranking method for decision-making problems in the bipolar neutrosophic environment. Pandy and Trinita [31] constructed a new approach to represent gray-scale (medical) images in the bipolar neutrosophic domain. Shazia et al. [32] presented the concept of the plithogenic hypersoft matrix and discussed some of its theoretical properties. Abdel-Basset et al. [17] developed the combination of quality function deployment with plithogenic operations and analyzed the case study of Thailand's sugar industry and also developed a novel evaluation approach to handle the hospital medical care systems based on plithogenic sets [16]. Azeddine et al. [34] introduced an improved method to map machine learning algorithms from crisp number to Neutrosophic environment. Wang and Smarandache (2010) focused on single-valued neutrosophic set [13] to magnetize on MADM problems. Chinnadurai et al., (2016) [3] discussed some of its theoretical properties. Smarandache and Teodorescu (2014) introduced the fusion of fuzzy data to neutrosophic data [11] with case studies. Garg and Nancy (2018) developed the neutrosophic Muirhead mean operators [5] for an aggregating single-valued neutrosophic set to solve MADM problems among the ambiguity. Gulistan et al., (2019) studied on neutrosophic cubic soft matrices [6] using max-min operations. Jun et al. presented elucidation to handle actual data which consists of crisp values using the neutrosophic analytic hierarchy process. Abdel-Basset et.al.

[12] developed the concept of Neutrosophic AHP-SWOT Analysis for MADM problems by analyzing a real case study.

The advantage of this proposed method is that it shortens the computation process and provides a better solution in decision-making. To establish the superiority of our improved score function a comparison study is illustrated with suitable examples. From the presented references [21, 22, 23, 24, 25, 26] it is clear that there are limitations in providing unique ranking using score function in neutrosophic MADM methods. The fact that we would like to enlighten in this manuscript is that there could always be a possibility of equal ranking among the alternatives. Hence, to our knowledge, a simple but effective way to determine the unique highest score for each object in a MADM is by including additional criteria from the parameter set which is not been discussed in any of the related literature works.

In this paper, we aim to discuss the weighted neutrosophic vector and value function of a neutrosophic soft matrix to combine the different components of truth, indeterminacy and falsity membership into a single membership value. An application of this matrix in MADM is also given by presenting the method, algorithm and numerical illustrations.

The structure of the manuscript is as follows. In section 2, some of the basic neutrosophic definitions are specified. In section 3, the notions of weighted neutrosophic vector and value functions are introduced. In section 4, an algorithm with a flowchart of NSM to MADM is developed. In section 5, case studies are presented to illustrate the working of the algorithm. This manuscript is concluded in section 6.

2. Preliminaries

In this section first we review some basic concepts and definitions.

Definition 2.1[9] Let U be the universal set and E be a set of parameters. The parameters represent some selected properties or characteristics of the elements of U. Let P(U) denote the power set of U. A pair (F, E) is called a **soft set** over U where F is a mapping $F: E \rightarrow P(U)$. It is clear that a soft set is a parameterized family of subsets of U.

Definition 2.2 [13] Let U be the universal set, then a set $\mathbb{A} = \{\langle x, T^{\mathbb{A}}(x), I^{\mathbb{A}}(x), F^{\mathbb{A}}(x)\rangle : x \in U\}$ is termed as **neutrosophic set** where $T^{\mathbb{A}}, I^{\mathbb{A}}, F^{\mathbb{A}}: X \rightarrow [0,1]$ with $0 \leq T^{\mathbb{A}}(x) + I^{\mathbb{A}}(x) + F^{\mathbb{A}}(x) \leq 3$ and the functions $T^{\mathbb{A}}, I^{\mathbb{A}}, F^{\mathbb{A}}$ are truth, indeterminacy and falsity membership degrees respectively.

Definition 2.3 [8] Let U be the universal set and E be a set of parameters. Consider $\mathbb{A} \subseteq E$. Let *NS(U)* denote the set of all neutrosophic sets of U. The collection $(F, \mathbb{A})$ is termed to be the **neutrosophic soft set** (NSS) over U, where F is a mapping given by $F: \mathbb{A} \rightarrow NS(U)$.

Definition 2.4 [4] Let $(N^{\mathbb{A}}, E)$ be a NSS over the universe U and E be a set of parameters and $\mathbb{A} \subseteq E$. Then a subset of $U \times E$ is uniquely defined by the relation $\{(x, e): e \in \mathbb{A}, x \in N^{\mathbb{A}}(e)\}$ and denoted by $R_{\mathbb{A}} = (N^{\mathbb{A}}, E)$. The relation $R_{\mathbb{A}}$ is characterized by truth function $T^{\mathbb{A}}: U \times E \rightarrow [0,1]$, indeterminacy $I^{\mathbb{A}}: U \times E \rightarrow [0,1]$ and the falsity function $F^{\mathbb{A}}: U \times E \rightarrow [0,1]$. $R_{\mathbb{A}}$ is represented as $R_{\mathbb{A}} = \{(T^{\mathbb{A}}(x, e), I^{\mathbb{A}}(x, e), F^{\mathbb{A}}(x, e)): 0 \leq T^{\mathbb{A}} + I^{\mathbb{A}} + F^{\mathbb{A}} \leq 3, (x, e) \in U \times E\}$. Now if the set of universe $U = \{x_1, x_2, \dots, x_m\}$ and the set of parameters $E = \{e_1, e_2, \dots, e_n\}$, then $R_{\mathbb{A}}$ can be represented by a matrix as follows:

$$R_{\mathbb{A}} = [a_{ij}]_{m\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

where $a_{ij} = (T^{\mathbb{A}}(x,e), I^{\mathbb{A}}(x,e), F^{\mathbb{A}}(x,e)) = \left(T_{ij}^{\mathbb{A}}, I_{ij}^{\mathbb{A}}, F_{ij}^{\mathbb{A}}\right)$.

The above matrix is called a **neutrosophic soft matrix** (NSM) of order $m\times$ n corresponding to the neutrosophic set $(N^{\mathbb{A}}, E)$ over U.

3. NSM theory in decision making

In this section, we define the concepts of weighted neutrosophic vector, score function and total score for a neutrosophic soft matrix. Later these notions will be used in MADM process.

Definition: 3.1 Let $\mathcal{M}$ be the collection of all neutrosophic values and $N = (n_1, n_2, \dots, n_n)$ be neutrosophic vector with components from $\mathcal{M}$. Thus the components of N are $N = ((n_1^T, n_1^I, n_1^F), (n_2^T, n_2^I, n_3^F), \dots, (n_n^T, n_n^I, n_n^F))$. Let $W = (w_1, w_2, \dots, w_n)$ be a weight vector associated with N. w_i can be considered as the significance attached to n_i; $i = 1,2,\dots,n$ with $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then the **weighted neutrosophic vector** corresponding to N and W denoted by WN is defined as $WN = (w_1n_1, w_2n_2, \dots, w_nn_n) = ((w_1n_1^T, w_1n_1^I, w_1n_1^F), (w_2n_2^T, w_2n_2^I, w_2n_2^F), \dots, (w_nn_n^T, w_nn_n^I, w_nn_n^F))$

Example:3.1 Let $N = ((0.4,0.3,0.6), (0.2,0.6,0.7), (0.7,0.1,0.5), (0.4,0.2,0.3))$ and $W = (0.1,0.4,0.2,0.3)$. Then $WN = ((0.04,0.03,0.06), (0.08,0.24,0.28), (0.14,0.02,0.10), (0.12,0.06,0.09))$

Definition: 3.2 Score function of a neutrosophic matrix helps to integrate the neutrosophic value into a single real number in order to bring out the importance of truth, indeterminacy and falsity membership values.

Let $A = [a_{ij}] = \left(T_{ij}^A, I_{ij}^A, F_{ij}^A\right)$. Then the score function for the element a_{ij} is defined as

$$s(a_{ij}) = s_{ij} = \frac{\left(T_{ij}^A + I_{ij}^A\right)}{2} + F_{ij}^A \;\forall\, i,j$$

Thus the **score function** for the NSM, $A = [a_{ij}]$ is given by

$$S_F(A) = \left[\frac{\left(T_{ij}^A + I_{ij}^A\right)}{2} + F_{ij}^A\right] = [s_{ij}].$$

$S_F(A)$ is also an $m\times n$ matrix, having the same dimension as A and has non-negative entries.

Definition 3.3 Let $N = [s_{ij}]$ be the matrix of score functions of a NSM N. The quantity $T_i = \sum_{j=1}^{n} s_{ij}$; $i = 1,2,\dots,m$ gives the **total of the score function** values for the i^{th} row of NSM. T_i represent the total value for the element x_i with representation to all the characteristics under consideration.

3.1 Comparison analysis with existing and proposed score functions

In this subsection, we compare and analyze the method developed in this paper with six of the recently developed score functions and methods. The below cited **Table 1** highlights the ranking difficulty of an existing score function in the neutrosophic environment. It also shows that the new score function can compute the rank of the alternatives even when the existing score function is unable to rank the alternatives.

Table 1. Comparison analysis of score values.

Neutrosophic environment	Existing & Proposed methods	Score value	Remarks
N_1=(0.6,0.2,0.6) & N_2=(0.6,0.4,0.2)	Sahin [25]	$S(N_1)$ = 0.3 & $S(N_2)$ = 0.3	$S(N_1)$ = $S(N_2)$ unable to rank
	Proposed method	**$S(N_1)$ = 1** & $S(N_2)$ = 0.7	**$S(N_1)$ > $S(N_2)$** able to rank
N_1=(0.7,0.3,0.1) & N_2=(0.9,0.4,0.2)	Peng et.al., [24]	$S(N_1)$ = 0.1 & $S(N_2)$ = 0.1	$S(N_1)$ = $S(N_2)$ unable to rank
	Proposed method	$S(N_1)$ = 0.60 & **$S(N_2)$ = 0.85**	**$S(N_2)$ > $S(N_1)$** able to rank
N_1=(0.9,0.6,0.3) & N_2=(0.6,0.4,0.2)	Garg and Nancy [23]	$S(N_1)$ = 0.26 & $S(N_2)$ = 0.26	$S(N_1)$ = $S(N_2)$ unable to rank
	Proposed method	**$S(N_1)$ = 1.05** & $S(N_2)$ = 0.7	**$S(N_1)$ > $S(N_2)$** able to rank
N_1=(0.4,0.2,0.6) & N_2=(0.7,0.6,0.7)	Arockiarani [21]	$S(N_1)$ = 0.28 & $S(N_2)$ = 0.28	$S(N_1)$ = $S(N_2)$ unable to rank
	Proposed method	$S(N_1)$ = 0.9 & **$S(N_2)$ = 1.35**	**$S(N_2)$ > $S(N_1)$** able to rank
N_1=(0.5,0.7,0.4) & N_2=(0.4,0.6,0.3)	Ye [26]	$S(N_1)$ = 0.55 & $S(N_2)$ = 0.55	$S(N_1)$ = $S(N_2)$ unable to rank
	Proposed method	**$S(N_1)$ = 1** & $S(N_2)$ = 0.8	**$S(N_1)$ > $S(N_2)$** able to rank
N_1=(0.8,0.3,0.2) & N_2=(0.6,0.3,0.7) N_3=(0.9,0.4,0.5) & N_4=(0.8,0.5,04)	Mondal [22]	$S(N_p)$ = 0.65, where p = 1,2 & $S(N_q)$ = 0.65 where q = 3,4	$S(N_p)$ = $S(N_q)$ unable to rank
	Proposed method	$S(N_p)$ = 0.95, where p = 1,2 & **$S(N_q)$ = 1.1** where q = 3,4	**$S(N_q)$ > $S(N_p)$** able to rank

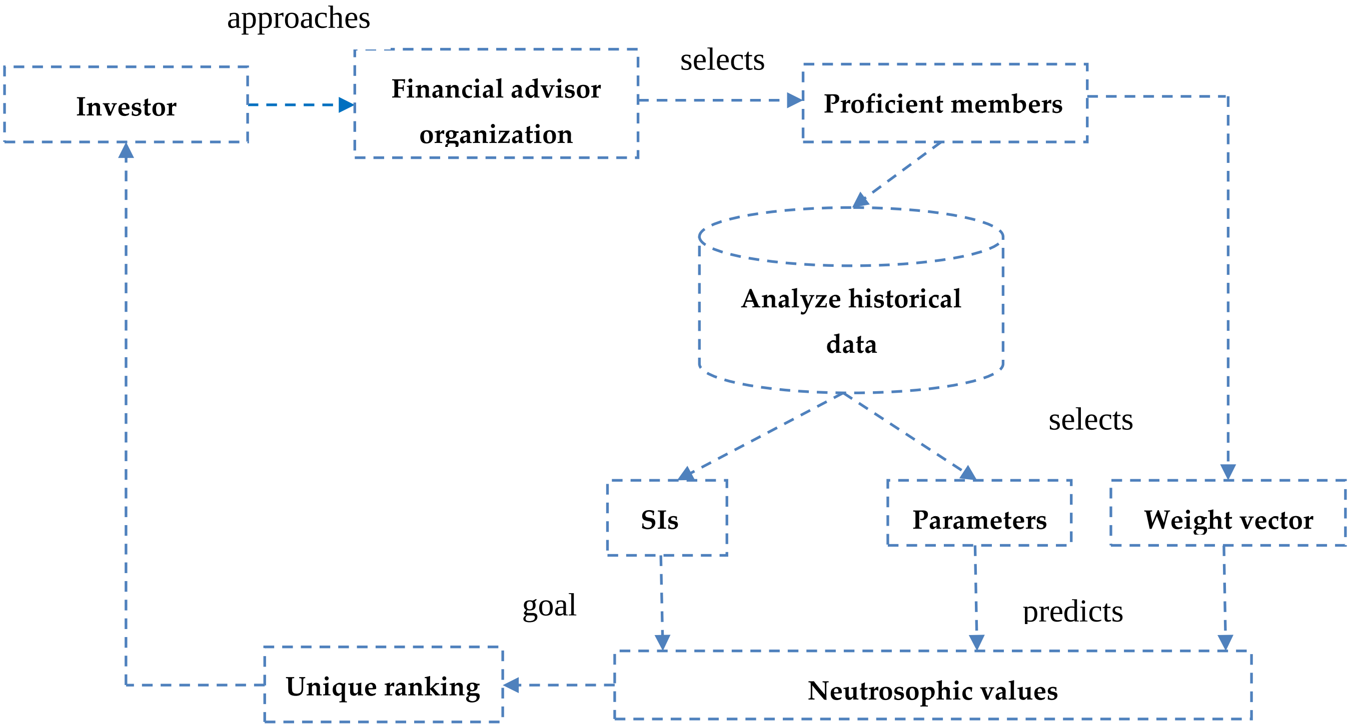
4. Application of NSM to MADM environment

In this section an application of NSM in MADM is explained. An algorithm is developed and the working of the same is illustrated with suitable examples.

4.1. Statement of the problem

Suppose a person is in the progression of stock investment (SI) in the equity market. Let's assume that person seeks the help of a financial advisor organization (FAO). FAO has a panel of highly-trained professionals to provide value-added services to the investors to ensure higher proficiency, consistency of charges and superior forecast of SI in equity market by analyzing the historical data. The FAO, in turn, selects a group of proficient members $P = \{p_1, p_2, \dots, p_k\}$ to proceed with the same. Now according to the group let $C = \{c_1, c_2, \dots, c_p\}$ be the list of selected SIs based on historical data analysis . Let $E = \{e_1, e_2, \dots, e_q\}$ be the set of selected parameters based on which the SIs selection is to be finalized. Assume that weights are assigned for each criterion. Let $W = (w_1, w_2, \dots, w_q)$ and $\sum_{i=1}^{q} w_i = 1$. Let's assume that the group assesses the SI based on a subset of the parameter set. Let $A = \{e_1, e_2, \dots, e_l\}$ be the subset of the parameter set E, so that $l \leq q$. Each of the personnel verifies the listed SI historical records based on the parameter set A and presents his forecast result in the form of neutrosophic soft matrices. The respective NSM's are denoted by $N^1, N^2, \dots, N^K$. The crisis is to convert the NSM's into significant matrices which enables them to select the best SI for the investor. **Figure 1** illustrates the conceptual structure of the problem.

Figure 1. Conceptual structure of the statement



4.2. Methodology

Let's assume that the proficient members evaluate the SIs independently without any bias. Let $N^1, N^2, \dots, N^K$ be the NSMs obtained from the members. Using **Definition 3.1**, and weight vector W the weighted neutrosophic matrices are calculated. The resultant of weighted neutrosophic matrices are denoted by $N_w^1, N_w^2, \dots, N_w^k$ i.e., $N_w^r = WN^r = [n_{ij}^r]$ where $r = 1,2, \dots, k$. Using **Definition 3.2**, convert each of the weighted neutrosophic matrix N_w^r value into corresponding score function as $S_F[N_w^r] = [s_{ij}^r] = \left[\frac{(T_{ij}^{rA} + I_{ij}^{rA})}{2} + F_{ij}^{rA}\right]$. Then using the **Definition 3.3** the score function for the i^{th} SI as evaluated by the r^{th} expert is calculated by adding the values of the i^{th} row of the score function matrix, ie., the i^{th} row of the weighted neutrosophic matrix N_w^r. Let us denote this sum by the symbol T_i^r. The total score ST_i for the i^{th} SI is obtained by summing T_i^r over r. That is the total score for the i^{th} SI $ST_i = \sum_{r=1}^{k} T_i^r = T_i^1 + T_i^2 + \cdots + T_i^k$. The total score is evaluated for all the SIs, $i = 1,2, \dots, p$. Arrange the ST_i values in decreasing order. The SI with highest ST_i value is the most suitable one for the investor. If more than one SI are there with equal highest ST_i value, the entire process is repeated by adding one more parameter into the set *A*. This process is repeated until a unique SI with highest ST_i value is identified.

4.3. Algorithm

The algorithm for ranking the alternatives of MADM problem based on NSM is given below:

Step 1: Identify the list of SIs and the list of parameters.

Step 2: Select a subset of the parameter set.

Step 3: Present the result in the form of NSMs $(N^1, N^2, \ldots, N^K)$.

Step 4: Compute the weight order for the NSMs $(N_W^1, N_W^2, \ldots, N_W^k)$.

Step 5: Calculate the score function matrix $S_F[N_w^r] = [s_{ij}^r]$

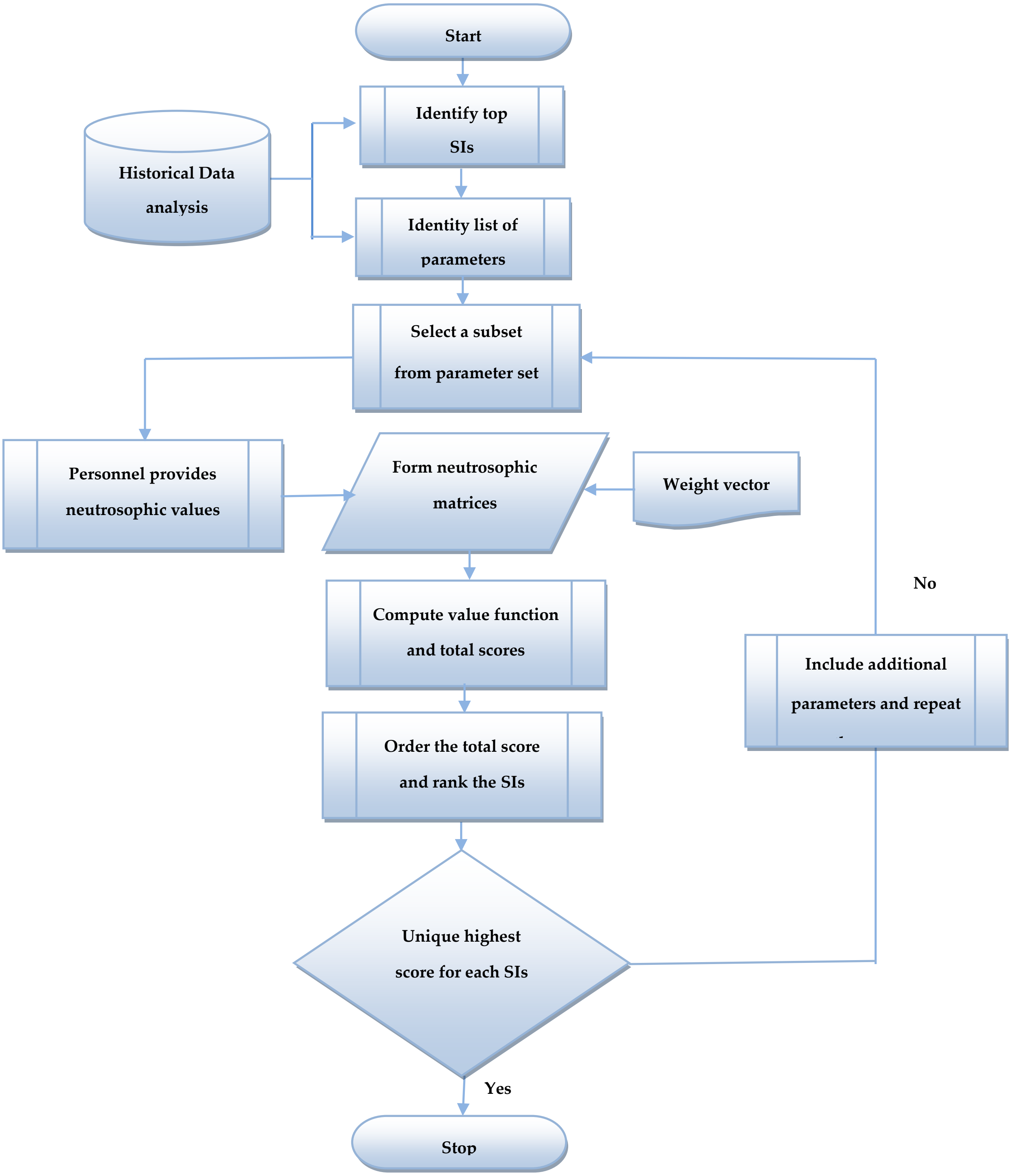
Step 6: Calculate the total value T_i^r from each of the $S_F[N_w^r]$ matrices.

Step 7: Evaluate the ST_i for each SI.

Step 8: Order the ST_i values and select the SI with highest ST_i value as the most suitable one.

Step 9: If there are more than one SI with equal highest ST_i value, repeat the process by including another parameter into the set *A*. Continue the process until a unique SI with highest ST_i is identified.

4.4. Flowchart



5. Case studies

In this section we present two case studies to illustrate the working of the algorithm. In 5.1 we present an example where the ranking of the SIs are unique and processed based on a subset of the criteria set. In 5.2 an example is given where the initially selected set of parameters does not provide unique ranking and there are more than one SIs with equal highest total score. Addition of another parameter yields a clear ranking and the selection is performed by repeating some of the steps with enlarged parameter set.

5.1. Case study I

A person is in the process of selecting a suitable SI.

1. Let $C = (c_1, c_2, \ldots, c_7)$ be the set of listed SIs.
2. Let $E = (e_1, e_2, e_3, e_4)$ be the set of parameters which form the criteria for selection.

Here, e_1 = financial profitability projection, e_2 = asset-utilization, e_3 = conservative capital structure and e_4 = earnings momentum.

3. Let the personnel present his forecast result in the form of NSM- N^1, N^2 and N^3 for the subset of the criteria set (e_1, e_2, e_3) as

$$N^1 = \begin{bmatrix} (0.245,0.456,0.721) & (0.457,0.421,0.431) & (0.415,0.821,0.211) \\ (0.348,0.156,0.627) & (0.345,0.653,0.543) & (0.618,0.712,0.514) \\ (0.546,0.765,0.429) & (0.765,0.753,0.632) & (0.415,0.521,0.416) \\ (0.267,0.321,0.321) & (0.552,0.893,0.723) & (0.314,0.612,0.518) \\ (0.428,0.416,0.891) & (0.452,0.213,0.413) & (0.231,0.923,0.916) \\ (0.456,0.932,0.217) & (0.569,0.236,0.247) & (0.416,0.378,0.612) \\ (0.324,0.634,0.816) & (0.367,0.456,0.912) & (0.482,0.231,0.712) \end{bmatrix}$$

$$N^2 = \begin{bmatrix} (0.245,0.348,0.546) & (0.456,0.156,0.765) & (0.721,0.627,0.429) \\ (0.457,0.345,0.765) & (0.421,0.653,0.753) & (0.431,0.543,0.632) \\ (0.415,0.618,0.415) & (0.821,0.712,0.521) & (0.211,0.514,0.416) \\ (0.238,0.416,0.467) & (0.734,0.817,0.926) & (0.518,0.456,0.267) \\ (0.314,0.231,0.916) & (0.753,0.893,0.213) & (0.213,0.765,0.457) \\ (0.753,0.893,0.213) & (0.618,0.415,0.314) & (0.451,0.233,0.532) \\ (0.412,0.824,0.218) & (0.614,0.425,0.324) & (0.546,0.267,0.428) \end{bmatrix} \text{ and}$$

$$N^3 = \begin{bmatrix} (0.238,0.734,0.518) & (0.765,0.345,0.734) & (0.345,0.457,0.347) \\ (0.416,0.817,0.456) & (0.429,0.653,0.817) & (0.456,0.892,0.821) \\ (0.467,0.926,0.267) & (0.156,0.543,0.926) & (0.673,0.452,0.342) \\ (0.914,0.316,0.912) & (0.245,0.431,0.211) & (0.345,0.763,0.821) \\ (0.928,0.419,0.745) & (0.348,0.345,0.618) & (0.543,0.821,0.721) \\ (0.211,0.518,0.213) & (0.245,0.456,0.721) & (0.436,0.417,0.556) \\ (0.156,0.653,0.712) & (0.348,0.345,0.618) & (0.529,0.673,0.719) \end{bmatrix}$$

4. Let the weight order of neutrosophic soft sets be $W_1 = 0.3, W_2 = 0.4, W_3 = 0.3$. Using **Definition 3.1** the results are obtained as

$$N_w^1 = \begin{bmatrix} (0.074,0.137,0.216) & (0.183,0.168,0.172) & (0.125,0.246,0.063) \\ (0.104,0.047,0.188) & (0.138,0.261,0.217) & (0.185,0.214,0.154) \\ (0.164,0.230,0.129) & (0.306,0.301,0.253) & (0.125,0.156,0.125) \\ (0.080,0.096,0.096) & (0.221,0.357,0.289) & (0.094,0.184,0.155) \\ (0.128,0.125,0.267) & (0.181,0.085,0.165) & (0.069,0.277,0.275) \\ (0.137,0.280,0.065) & (0.228,0.094,0.099) & (0.125,0.113,0.184) \\ (0.097,0.190,0.245) & (0.147,0.182,0.365) & (0.145,0.069,0.214) \end{bmatrix},$$

$$N_w^2 = \begin{bmatrix} (0.074,0.104,0.164) & (0.182,0.062,0.306) & (0.216,0.188,0.129) \\ (0.137,0.104,0.230) & (0.168,0.261,0.301) & (0.129,0.163,0.190) \\ (0.125,0.185,0.125) & (0.328,0.285,0.208) & (0.063,0.154,0.125) \\ (0.071,0.125,0.140) & (0.294,0.327,0.370) & (0.155,0.137,0.080) \\ (0.094,0.069,0.275) & (0.301,0.357,0.085) & (0.064,0.230,0.137) \\ (0.226,0.268,0.064) & (0.247,0.166,0.126) & (0.135,0.070,0.160) \\ (0.124,0.247,0.065) & (0.246,0.170,0.130) & (0.164,0.080,0.128) \end{bmatrix} and$$

$$N_w^3 = \begin{bmatrix} (0.071,0.220,0.155) & (0.306,0.138,0.294) & (0.104,0.137,0.104) \\ (0.125,0.245,0.137) & (0.172,0.261,0.327) & (0.137,0.268,0.246) \\ (0.140,0.278,0.080) & (0.062,0.217,0.370) & (0.202,0.136,0.103) \\ (0.274,0.095,0.274) & (0.098,0.172,0.084) & (0.104,0.229,0.246) \\ (0.278,0.126,0.224) & (0.139,0.138,0.247) & (0.163,0.246,0.216) \\ (0.063,0.155,0.064) & (0.098,0.182,0.288) & (0.131,0.125,0.167) \\ (0.047,0.196,0.214) & (0.139,0.138,0.247) & (0.159,0.202,0.216) \end{bmatrix}$$

5. Using **Definition 3.2** the score function matrices are obtained as

$$S_F(N_w^1) = \begin{bmatrix} 0.321 & 0.348 & 0.249 \\ 0.264 & 0.417 & 0.354 \\ 0.325 & 0.556 & 0.265 \\ 0.185 & 0.578 & 0.294 \\ 0.394 & 0.298 & 0.448 \\ 0.273 & 0.260 & 0.303 \\ 0.389 & 0.529 & 0.321 \end{bmatrix} S_F(N_w^2) = \begin{bmatrix} 0.253 & 0.428 & 0.331 \\ 0.350 & 0.516 & 0.336 \\ 0.279 & 0.515 & 0.234 \\ 0.238 & 0.681 & 0.226 \\ 0.357 & 0.414 & 0.284 \\ 0.311 & 0.332 & 0.262 \\ 0.251 & 0.337 & 0.250 \end{bmatrix} S_F(N_w^3) =$$

$$\begin{bmatrix} 0.301 & 0.516 & 0.224 \\ 0.322 & 0.543 & 0.449 \\ 0.289 & 0.510 & 0.271 \\ 0.458 & 0.220 & 0.413 \\ 0.426 & 0.386 & 0.421 \\ 0.173 & 0.429 & 0.295 \\ 0.335 & 0.386 & 0.396 \end{bmatrix}$$

6. Applying **Definition 3.3** the total of the score functions are calculated as

$$T_i^1 = \begin{bmatrix} 0.918 \\ 1.034 \\ 1.147 \\ 1.057 \\ 1.140 \\ 0.836 \\ 1.238 \end{bmatrix}, T_i^2 = \begin{bmatrix} 1.012 \\ 1.202 \\ 1.028 \\ 1.145 \\ 1.055 \\ 0.905 \\ 1.839 \end{bmatrix} and\ T_i^3 = \begin{bmatrix} 1.041 \\ 1.313 \\ 1.071 \\ 1.090 \\ 1.232 \\ 0.897 \\ 1.117 \end{bmatrix}$$

7. The total value for each candidate is calculated and presented as

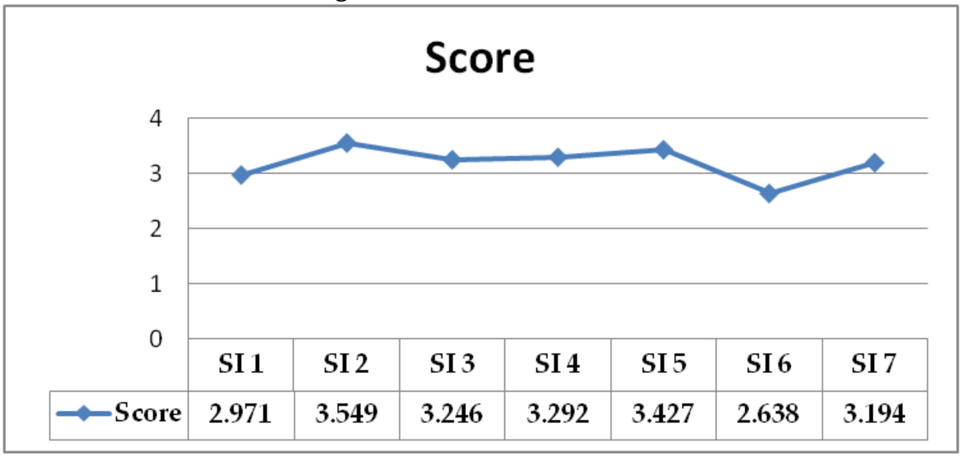
$$ST_i = \begin{bmatrix} 2.971 \\ 3.549 \\ 3.246 \\ 3.292 \\ 3.427 \\ 2.638 \\ 3.194 \end{bmatrix}$$

8. Arranging the SIs according to their total score values we obtain the ranking of the SIs as

Table 2. Tabular representation of SI's total score values.

c_i	Score	Rank
$\boldsymbol{c_2}$	**3.549**	**1**
c_5	3.427	2
c_4	3.292	3
c_3	3.246	4
c_7	3.194	5
c_1	2.971	6
c_6	2.638	7

Figure 2. Score values of SIs.



From **Table 2** and **Figure 2**, we obtain the ranking of SIs as $c_2 > c_5 > c_4 > c_3 > c_7 > c_1 > c_6$. The SI c_2 ranks first and it is the most suitable SI for the investor.

5.2. Case study II

Consider the same example as in 5.1. A person would like to select the best SI.

1. Let $C = (c_1, c_2, \ldots, c_7)$ be the set of top listed SIs.

2. Let $E = (e_1, e_2, e_3, e_4)$ be the set of parameters which form the criteria for selection. Here, e_1 = financial profitability projection, e_2 = asset-utilization, e_3 = conservative capital structure and e_4 = earnings momentum of the SI.

3. Let the personnel present his forecast result in the form of NSM- N^1, N^2 and N^3 for the subset of the criteria set (e_1, e_2, e_3) as

$$N^1 = \begin{bmatrix} (0.245,0.456,0.721) & (0.457,0.421,0.431) & (0.415,0.821,0.211) \\ (0.247,0.156,0.547) & (0.345,0.653,0.543) & (0.618,0.712,0.614) \\ (0.546,0.765,0.429) & (0.765,0.753,0.632) & (0.415,0.521,0.416) \\ (0.567,0.552,0.521) & (0.652,0.682,0.723) & (0.313,0.412,0.568) \\ (0.429,1.000,0.891) & (0.452,0.219,0.407) & (0.231,0.922,0.916) \\ (0.456,0.932,0.217) & (0.569,0.236,0.247) & (0.416,0.378,0.612) \\ (0.324,0.634,0.816) & (0.367,0.456,0.912) & (0.482,0.231,0.712) \end{bmatrix},$$

$$N^2 = \begin{bmatrix} (0.245,0.348,0.546) & (0.456,0.156,0.765) & (0.721,0.627,0.429) \\ (0.457,0.345,0.765) & (0.421,0.653,0.753) & (0.431,0.543,0.632) \\ (0.415,0.618,0.415) & (0.821,0.712,0.521) & (0.211,0.514,0.416) \\ (0.638,0.516,0.467) & (0.734,0.817,0.926) & (0.518,0.456,0.467) \\ (0.314,0.231,0.916) & (0.753,0.893,0.213) & (0.213,0.765,0.457) \\ (0.753,0.893,0.213) & (0.618,0.415,0.314) & (0.451,0.233,0.532) \\ (0.412,0.824,0.218) & (0.614,0.425,0.324) & (0.546,0.267,0.428) \end{bmatrix} and$$

$$N^3 = \begin{bmatrix} (0.238,0.734,0.518) & (0.765,0.345,0.734) & (0.345,0.457,0.347) \\ (0.416,0.817,0.456) & (0.429,0.753,0.817) & (0.456,0.892,0.821) \\ (0.467,0.926,0.267) & (0.156,0.543,0.926) & (0.673,0.452,0.342) \\ (0.714,0.716,0.912) & (0.245,0.431,0.211) & (0.345,0.763,0.821) \\ (0.928,0.419,0.745) & (0.348,0.345,0.616) & (0.543,0.821,0.721) \\ (0.211,0.518,0.213) & (0.245,0.456,0.721) & (0.436,0.417,0.556) \\ (0.156,0.653,0.712) & (0.348,0.345,0.618) & (0.529,0.673,0.719) \end{bmatrix}$$

4. Let the weight order of neutrosophic soft sets be $W_1 = 0.3, W_2 = 0.4, W_3 = 0.3$. Using Definition 3.1 the results are obtained as

$$N_w^1 = \begin{bmatrix} (0.074,0.137,0.216) & (0.183,0.168,0.172) & (0.125,0.246,0.063) \\ (0.074,0.047,0.164) & (0.138,0.261,0.217) & (0.184,0.214,0.184) \\ (0.164,0.230,0.129) & (0.306,0.301,0.253) & (0.125,0.156,0.125) \\ (0.070,0.166,0.156) & (0.261,0.273,0.289) & (0.094,0.124,0.170) \\ (0.129,0.300,0.267) & (0.181,0.088,0.163) & (0.069,0.277,0.275) \\ (0.137,0.280,0.065) & (0.228,0.094,0.099) & (0.125,0.113,0.184) \\ (0.097,0.190,0.245) & (0.147,0.182,0.365) & (0.145,0.069,0.213) \end{bmatrix},$$

$$N_w^2 = \begin{bmatrix} (0.074,0.104,0.164) & (0.182,0.062,0.306) & (0.216,0.188,0.129) \\ (0.137,0.104,0.230) & (0.168,0.261,0.301) & (0.129,0.163,0.190) \\ (0.125,0.185,0.125) & (0.328,0.285,0.208) & (0.063,0.154,0.125) \\ (0.091,0.155,0.140) & (0.294,0.327,0.370) & (0.155,0.137,0.140) \\ (0.094,0.069,0.275) & (0.301,0.357,0.085) & (0.064,0.230,0.137) \\ (0.226,0.268,0.064) & (0.247,0.166,0.126) & (0.135,0.070,0.160) \\ (0.124,0.247,0.065) & (0.246,0.170,0.130) & (0.164,0.080,0.128) \end{bmatrix} and$$

$$N_w^3 = \begin{bmatrix} (0.071,0.220,0.155) & (0.306,0.138,0.294) & (0.104,0.137,0.104) \\ (0.125,0.245,0.137) & (0.172,0.301,0.327) & (0.137,0.268,0.246) \\ (0.140,0.278,0.080) & (0.062,0.217,0.370) & (0.202,0.136,0.103) \\ (0.214,0.215,0.274) & (0.098,0.172,0.084) & (0.104,0.229,0.246) \\ (0.278,0.126,0.224) & (0.139,0.138,0.246) & (0.163,0.246,0.216) \\ (0.063,0.155,0.064) & (0.098,0.182,0.288) & (0.131,0.125,0.167) \\ (0.047,0.196,0.214) & (0.139,0.138,0.247) & (0.159,0.202,0.216) \end{bmatrix}$$

5. Using **Definition 3.2** the score function matrices are obtained as

$$V_F(N_w^1) = \begin{bmatrix} 0.321 & 0.348 & 0.249 \\ 0.225 & 0.417 & 0.384 \\ 0.325 & 0.556 & 0.265 \\ 0.324 & 0.556 & 0.279 \\ 0.482 & 0.297 & 0.448 \\ 0.273 & 0.260 & 0.303 \\ 0.389 & 0.529 & 0.321 \end{bmatrix} V_F(N_w^2) = \begin{bmatrix} 0.253 & 0.428 & 0.331 \\ 0.350 & 0.516 & 0.336 \\ 0.279 & 0.515 & 0.234 \\ 0.313 & 0.681 & 0.286 \\ 0.357 & 0.414 & 0.284 \\ 0.311 & 0.332 & 0.262 \\ 0.251 & 0.337 & 0.250 \end{bmatrix} V_F(N_w^3) = \begin{bmatrix} 0.301 & 0.516 & 0.224 \\ 0.322 & 0.563 & 0.449 \\ 0.289 & 0.510 & 0.271 \\ 0.488 & 0.220 & 0.413 \\ 0.426 & 0.385 & 0.421 \\ 0.173 & 0.429 & 0.295 \\ 0.335 & 0.386 & 0.396 \end{bmatrix}$$

6. Applying **Definition 3.3** the total of the score functions are calculated as

$$T_i^1 = \begin{bmatrix} 0.918 \\ 1.025 \\ 1.147 \\ 1.159 \\ 1.226 \\ 0.836 \\ 1.238 \end{bmatrix}, T_i^2 = \begin{bmatrix} 1.012 \\ 1.202 \\ 1.028 \\ 1.280 \\ 1.055 \\ 0.905 \\ 1.839 \end{bmatrix}, T_i^3 = \begin{bmatrix} 1.041 \\ 1.333 \\ 1.071 \\ 1.120 \\ 1.231 \\ 0.897 \\ 1.117 \end{bmatrix},$$

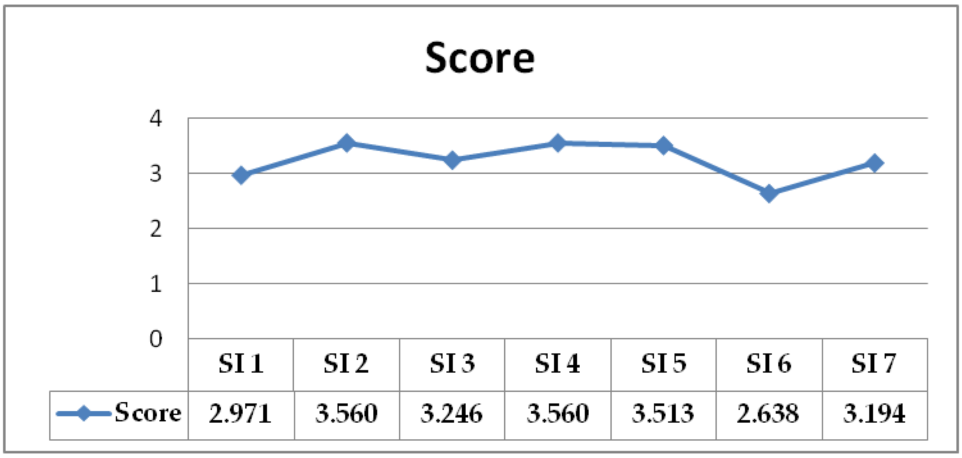
7. The total value for each SI is calculated and presented as

$$ST_i = \begin{bmatrix} 2.971 \\ 3.560 \\ 3.246 \\ 3.560 \\ 3.513 \\ 2.638 \\ 3.194 \end{bmatrix}$$

Table 3. Tabular representation of SI's total score values.

$\boldsymbol{c_i}$	**Score**	**Rank**
$\boldsymbol{c_2}$	**3.560**	**1**
$\boldsymbol{c_4}$	**3.560**	**1**
c_5	3.513	3
c_3	3.246	4
c_7	3.194	5
c_1	2.971	6
c_6	2.638	7

Figure 3. Score values of SIs



From **Table 3** and **Figure 3**, we obtain the ranking of SIs as $c_2 = c_4 > c_5 > c_3 > c_7 > c_1 > c_6$. As there are more than one SI $(c_2$ and $c_4)$ with the same ranking we add one more parameter e_4 in the list and repeat the process.

$$N^1 = \begin{bmatrix} (0.245,0.456,0.721) & (0.457,0.421,0.431) & (0.415,0.821,0.211) & (0.536,0.665,0.129) \\ (0.247,0.156,0.547) & (0.345,0.653,0.543) & (0.618,0.712,0.614) & (0.547,0.451,0.321) \\ (0.546,0.765,0.429) & (0.765,0.753,0.632) & (0.415,0.521,0.416) & (0.357,0.451,0.631) \\ (0.567,0.552,0.521) & (0.652,0.682,0.723) & (0.313,0.412,0.568) & (0.375,0.753,0.243) \\ (0.429,1.000,0.891) & (0.452,0.219,0.407) & (0.231,0.922,0.916) & (0.251,0.562,0.726) \\ (0.456,0.932,0.217) & (0.569,0.236,0.247) & (0.416,0.378,0.612) & (0.426,0.478,0.512) \\ (0.324,0.634,0.816) & (0.367,0.456,0.912) & (0.482,0.231,0.712) & (0.416,0.252,0.317) \end{bmatrix},$$

$$N^2 = \begin{bmatrix} (0.245,0.348,0.546) & (0.456,0.156,0.765) & (0.721,0.627,0.429) & (0.546,0.765,0.429) \\ (0.457,0.345,0.765) & (0.421,0.653,0.753) & (0.431,0.543,0.632) & (0.567,0.551,0.521) \\ (0.415,0.618,0.415) & (0.821,0.712,0.521) & (0.211,0.514,0.416) & (0.457,0.421,0.431) \\ (0.638,0.516,0.467) & (0.734,0.817,0.926) & (0.518,0.456,0.467) & (0.345,0.653,0.543) \\ (0.314,0.231,0.916) & (0.753,0.893,0.213) & (0.213,0.765,0.457) & (0.231,0.922,0.916) \\ (0.753,0.893,0.213) & (0.618,0.415,0.314) & (0.451,0.233,0.532) & (0.416,0.378,0.612) \\ (0.412,0.824,0.218) & (0.614,0.425,0.324) & (0.546,0.267,0.428) & (0.456,0.932,0.217) \end{bmatrix}$$

$$N^3 = \begin{bmatrix} (0.238,0.734,0.518) & (0.765,0.345,0.734) & (0.721,0.627,0.429) & (0.546,0.765,0.429) \\ (0.416,0.817,0.456) & (0.429,0.753,0.817) & (0.431,0.543,0.632) & (0.567,0.551,0.521) \\ (0.467,0.926,0.267) & (0.156,0.543,0.926) & (0.211,0.514,0.416) & (0.457,0.421,0.431) \\ (0.714,0.716,0.912) & (0.245,0.431,0.211) & (0.518,0.456,0.467) & (0.345,0.653,0.543) \\ (0.928,0.419,0.745) & (0.348,0.345,0.616) & (0.213,0.765,0.457) & (0.231,0.922,0.916) \\ (0.211,0.518,0.213) & (0.245,0.456,0.721) & (0.451,0.233,0.532) & (0.416,0.378,0.612) \\ (0.156,0.653,0.712) & (0.348,0.345,0.618) & (0.546,0.267,0.428) & (0.456,0.932,0.217) \end{bmatrix},$$

4. Let the weight order of neutrosophic soft sets be $W_1 = 0.3, W_2 = 0.4, W_3 = 0.15$ and $W_4 = 0.15$. Using **Definition 3.1** the resultant are obtained as

$$N_w^1 = \begin{bmatrix} (0.074,0.137,0.216) & (0.183,0.168,0.172) & (0.062,0.123,0.032) & (0.080,0.100,0.019) \\ (0.074,0.047,0.164) & (0.138,0.261,0.217) & (0.093,0.107,0.092) & (0.082,0.068,0.048) \\ (0.164,0.230,0.129) & (0.306,0.301,0.253) & (0.062,0.078,0.062) & (0.054,0.068,0.095) \\ (0.070,0.166,0.156) & (0.261,0.273,0.289) & (0.047,0.062,0.085) & (0.056,0.113,0.036) \\ (0.129,0.300,0.267) & (0.181,0.088,0.163) & (0.035,0.138,0.137) & (0.038,0.084,0.109) \\ (0.137,0.280,0.065) & (0.228,0.094,0.099) & (0.062,0.057,0.092) & (0.064,0.072,0.077) \\ (0.097,0.190,0.245) & (0.147,0.182,0.365) & (0.072,0.035,0.107) & (0.062,0.038,0.048) \end{bmatrix}$$

$$N_w^2 = \begin{bmatrix} (0.074,0.104,0.164) & (0.182,0.062,0.306) & (0.108,0.094,0.064) & (0.082,0.115,0.064) \\ (0.137,0.104,0.230) & (0.168,0.261,0.301) & (0.065,0.081,0.095) & (0.085,0.083,0.078) \\ (0.125,0.185,0.125) & (0.328,0.285,0.208) & (0.032,0.077,0.062) & (0.069,0.063,0.065) \\ (0.091,0.155,0.140) & (0.294,0.327,0.370) & (0.078,0.068,0.070) & (0.052,0.098,0.081) \\ (0.094,0.069,0.275) & (0.301,0.357,0.085) & (0.032,0.115,0.069) & (0.035,0.138,0.137) \\ (0.226,0.268,0.064) & (0.247,0.166,0.126) & (0.068,0.035,0.080) & (0.062,0.057,0.092) \\ (0.124,0.247,0.065) & (0.246,0.170,0.130) & (0.082,0.040,0.064) & (0.068,0.140,0.033) \end{bmatrix}$$

$$N_w^3 = \begin{bmatrix} (0.071,0.220,0.155) & (0.306,0.138,0.294) & (0.052,0.069,0.052) & (0.082,0.115,0.064) \\ (0.125,0.245,0.137) & (0.172,0.301,0.327) & (0.068,0.134,0.123) & (0.085,0.083,0.078) \\ (0.140,0.278,0.080) & (0.062,0.217,0.370) & (0.101,0.068,0.051) & (0.069,0.063,0.065) \\ (0.214,0.215,0.274) & (0.098,0.172,0.084) & (0.052,0.114,0.123) & (0.052,0.098,0.081) \\ (0.278,0.126,0.224) & (0.139,0.138,0.246) & (0.081,0.123,0.108) & (0.035,0.138,0.137) \\ (0.063,0.155,0.064) & (0.098,0.182,0.288) & (0.065,0.063,0.083) & (0.062,0.057,0.092) \\ (0.047,0.196,0.214) & (0.139,0.138,0.247) & (0.079,0.101,0.108) & (0.068,0.140,0.033) \end{bmatrix}$$

5. Using **Definition 3.2** the score function matrices are obtained as

$$V_F(N_w^1) = \begin{bmatrix} 0.321 & 0.348 & 0.124 & 0.109 \\ 0.225 & 0.417 & 0.192 & 0.123 \\ 0.325 & 0.556 & 0.133 & 0.155 \\ 0.324 & 0.556 & 0.140 & 0.121 \\ 0.482 & 0.297 & 0.224 & 0.170 \\ 0.273 & 0.260 & 0.151 & 0.145 \\ 0.389 & 0.529 & 0.160 & 0.098 \end{bmatrix}, V_F(N_w^2) = \begin{bmatrix} 0.253 & 0.428 & 0.165 & 0.163 \\ 0.350 & 0.516 & 0.168 & 0.162 \\ 0.279 & 0.515 & 0.117 & 0.131 \\ 0.313 & 0.681 & 0.143 & 0.156 \\ 0.357 & 0.414 & 0.142 & 0.224 \\ 0.311 & 0.332 & 0.131 & 0.151 \\ 0.251 & 0.337 & 0.125 & 0.137 \end{bmatrix}$$

$$V_F(N_w^3) = \begin{bmatrix} 0.301 & 0.516 & 0.112 & 0.163 \\ 0.322 & 0.563 & 0.224 & 0.162 \\ 0.289 & 0.510 & 0.136 & 0.131 \\ 0.488 & 0.220 & 0.206 & 0.156 \\ 0.426 & 0.385 & 0.210 & 0.224 \\ 0.173 & 0.429 & 0.147 & 0.151 \\ 0.335 & 0.386 & 0.198 & 0.137 \end{bmatrix}$$

6. Applying **Definition 3.3** the total of the score functions are calculated as

$$T_i^1 = \begin{bmatrix} 0.903 \\ 0.995 \\ 1.170 \\ 1.141 \\ 1.130 \\ 0.829 \\ 1.176 \end{bmatrix}, T_i^2 = \begin{bmatrix} 1.009 \\ 1.196 \\ 1.293 \\ 1.137 \\ 0.925 \\ 0.850 \end{bmatrix} and T_i^3 = \begin{bmatrix} 1.092 \\ 1.271 \\ 1.065 \\ 1.070 \\ 1.245 \\ 0.901 \\ 1.055 \end{bmatrix}$$

7. The total value for each SI is calculated and presented as

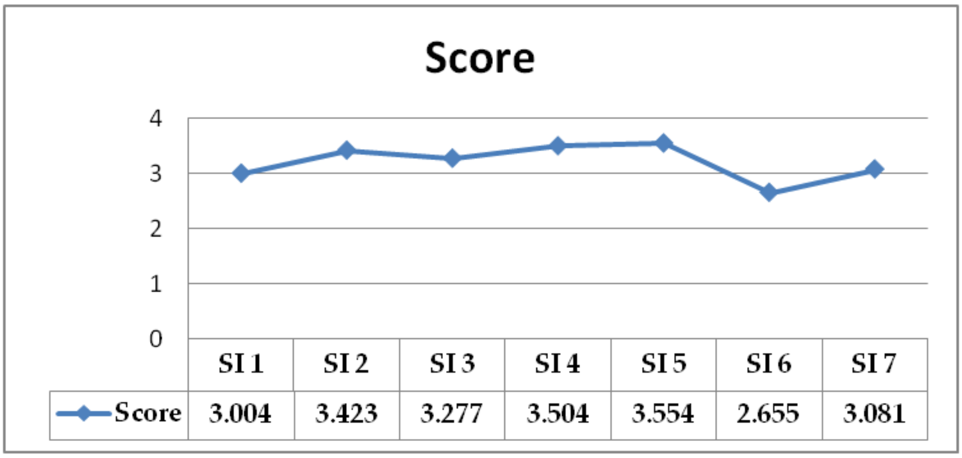
$$ST_i = \begin{bmatrix} 3.004 \\ 3.423 \\ 3.277 \\ 3.504 \\ 3.554 \\ 2.655 \\ 3.081 \end{bmatrix}$$

8. Arranging the SIs according to their total score values we obtain the ranking of the SIs as

Table 4. Tabular representation of SI's total score values.

c_i	Score	Rank
c_5	**3.554**	**1**
c_4	3.504	2
c_2	3.423	3
c_3	3.277	4
c_7	3.081	5
c_1	3.004	6
c_6	2.655	7

Figure 4. Score values of SIs



From **Table 4** and **Figure 4**, we obtain the ranking of SIs as $c_5 > c_4 > c_2 > c_3 > c_7 > c_1 > c_6$. The SI c_5 ranks first and it is the most suitable SI for the investor.

6. Conclusions

The proposed NSM computational solution supports decision-makers in solving the complex decision-making problem faced in today's ambiguity situation. In this paper, the weight vector and score function are introduced with illustrative examples. By applying the score function we solve the MADM problems in the neutrosophic environment and transforming the values of truth, indeterminacy and falsity into a single membership value to obtain a more precise, efficient, and realistic solution. An application of NSM in MADM is also explained. An algorithm is developed for this purpose and two examples are provided to illustrate the working of the algorithm. Our future work is to extend the concept of MADM problems in real-life psychology applications by using standard or hybrid neutrosophic and plithogenic tools.

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