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Research Article

A Multi Criteria Decision Making Approach Based on Stability of Expert's Opinions Under Uncertain Environment

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Abstract

Decision making (DM) in uncertain environments remains a significant challenge due to incomplete information, ambiguity and the unpredictable nature. In uncertain environments effective decision making method helps to minimize risks by evaluating possible outcomes and selecting the most suitable option. Naturally human thinking often involves uncertainty and hesitation. In many real world situations, data may also be contradictory. Neutrosophic set (NS) manage uncertainty by offering its flexible representation to express uncertainty, impreciseness, incompleteness and inconsistency. NS facilitate DM by representing truth, falsity and indeterminacy simultaneously associated with uncertain information. Vector methods provide an effective mathematical approach to represent and analysis quantities involving magnitude and direction. The degrees of truth, indeterminacy and falsity of NS can be effectively represented as a vector in Cartesian coordinates, providing a more intuitive geometric visualization of neutrosophic information. Consequently, vector-based operations can be employed to facilitate the analysis and comparison of neutrosophic information in DM problems. This paper focuses on a DM method determined by the stability of expert's opinions by considering NS as a vector valued function. The method has been discussed step by step theoretically and a numerical illustration is provided, leading to decisions that are more reliable under uncertain and incomplete information.

Keywords

Decision Making, Multi Criteria Decision Making (MCDM), Neutrosophic Set as Vector Valued Function

1. Introduction

DM is a fundamental activity in both personal life and organizational management. It helps in selecting the best course of action among alternatives. Proper decisions ensure optimal utilization of limited resources such as time, money and manpower. On the other hand uncertainty is a common phenomenon - indeed a universal and unavoidable part of life. previous research works in uncertainty theory [32, 33], in uncertain logic [34], uncertain risk analysis and uncertain reliable analysis [35] have been successfully carried out. In uncertain environment, effective decision making helps to minimize risks by evaluating possible outcomes and selecting the most suitable option. Decision making is critical because it guides actions, reduces uncertainty and plays a key role in achieving success in both personal and professional contents. Gonzalez-Mendoza et al. [20] showed that it is necessary to be aware of three types of biases of decision makers which can lead to irrational decisions. Decisions have to take under uncertain environment. Various kinds of decision making problems have been handled in [1–3, 5, 6, 8, 28–30, 36, 37] using different techniques. Fuzzy set (FS)(in 1965) concept [9] was established by Zadeh. After innovation of FS theory, Atanasov [4] presented intuitionistic fuzzy set, introducing membership and non membership grade.

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NS is more genaralized invented by Smarandache [10]. The practical significance of NS is attributed to their ability to handle truth, falsity and indeterminacy simultaneously. Human thinking often involves uncertainty and hesitation. NS mimic this by including the indeterminacy components making models more realistic. A NS is essentially a three dimensional vector, making it mathematically compatible with vector algebra and geometry. It allows vector operations such as vector addition, scalar multiplication, distance measurement and similarity computation to be applied to neutrosophic information. Neutrosophic models have been implemented to various medical DM problems, highlighting their advantages in handling uncertainty [1, 11, 13–15, 21–23]. Moreover, research on physician selection utilizing neutrosophic multi-criteria decision-making methods has demonstrated its practical utility in healthcare settings [24]. Refined neutrosophic fuzzy logic has shown significant potential in managing ambiguous medical data [23]. Similarity measure, an important tool to compare neutrosopic data, has been used in various research papers [6, 7, 17, 18, 22] and finally applied to decision making problems. Minimum spannig tree problem [31] was solved by Mandal and Basu using similarity measure between NSs. They [25] also developed aggregation operator & score function to rank single valued neutrosophic sets (SVNSs) and solved neutrosophic-based MCDM problem.

In the proposed study, a novel DM approach by considering neutrosophic number as three dimensional vector is introduced to select the best opinion given by several experts. Main advantage of this method is vector representation of neutrosophic number always provides a reasonable and mathematical consistent result by effectively combining multiple attributes into a single framework for decision making.

2. Neutrosophic Sets [10]

2.1. Definition

Let U be an universe of discourse then the neutrosophic set A is defined as $A = \{\langle x : T_A(x), I_A(x), F_A(x)\rangle, x \in U\}$, where the functions T, I, F: U $\rightarrow$ $]^-0, 1^+[$ define respectively the degree of membership (or Truth), the degree of indeterminacy and the degree of non-membership (or falsehood) of the element $x \in U$ to the set A with the condition $^-0 \leq T_A(x)+I_A(x)+F_A(x) \leq 3^+$.

2.2. Simplified Neutrosophic Set [19]

Let X be a space of points (objects) with generic elements in X denoted by x. An neutrosophic set A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy membership function $I_A(x)$, and a falsity-membership function $F_A(x)$, if the functions $T_A(x), I_A(x), F_A(x)$ are singletone subintervals/subsets in the real standard $[0, 1]$, i.e., $T_A(x) : X \rightarrow [0, 1]$, $I_A(x) : X \rightarrow [0, 1]$ and $F_A(x) : X \rightarrow [0, 1]$. Then a simplification of the neutrosophic set A is denoted by $A = \{\langle x, T_A(x), I_A(x), F_A(x)\rangle, x \in X\}$.

2.3. Single Valued Neutrosophic Sets (SVNS) [16]

Let X be a space of points (objects) with generic elements in X denoted by x. An SVNS A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy membership function $I_A(x)$ and a falsity-membership function $F_A(x)$, for each point $x \in X$, $T_A(x), I_A(x), F_A(x) \in [0, 1]$. Therefore, a SVNS A can be written as $A_{SVNS} = \{\langle x, T_A(x), I_A(x), F_A(x)\rangle, x \in X\}$. For two SVNS, $A_{SVNS} = \{\langle x, T_A(x), I_A(x), F_A(x)\rangle, x \in X\}$ and $B_{SVNS} = \{\langle x, T_B(x), I_B(x), F_B(x)\rangle, x \in X\}$, the following

$A_{NS} \subseteq B_{NS}$ if and only if $T_A(x) \leq T_B(x)$, $I_A(x) \geq I_B(x)$, $F_A(x) \geq F_B(x)$.

$A_{NS} = B_{NS}$ if and only if $T_A(x) = T_B(x)$, $I_A(x) = I_B(x)$, $F_A(x) = F_B(x)$.

$A^c = \langle x, F_A(x), 1 - I_A(x), T_A(x)\rangle$.

2.4. Vector Representation of a Neutrosophic Set

Define a function $f_A : X \rightarrow \mathbb{R}^3$ by $f_A(x) = (T_A(x), I_A(x), F_A(x))$, $T_A(x), I_A(x), F_A(x) \in [0, 1]$. Thus each element $x \in X$ is associated with a three dimensional vector representing its truth, indeterminacy and falsity degrees.

Operational relations: addition, subtraction and multiplication between $A = (T_A, I_A, F_A)$ and $B = (T_B, I_B, F_B)$ are defined as follows: $A + B = (min\{T_A + T_B, 1\}, min\{I_A + I_B, 1\}, min\{F_A + F_B, 1\})$. $A - B =$
$(min\{|T_A - T_B|, 1\}, min\{|I_A - I_B|, 1\}, min\{|F_A - F_B|, 1\})$.
And $AB = (T_AT_B, I_AI_B, F_AF_B)$

2.5. Similarity Measure [27]

Similarity measure S for SVNS(X) is a real function on universe X such that $S : SVNS(X) \times SVNS(X) \rightarrow [0, 1]$ and satisfies the following properties: (i) $0 \leq s(A, B) \leq 1, \forall A, B \in SVNS(X)$,

(ii) $s(A, B) = s(B, A), \forall A, B \in SVNS(X)$,

(iii) $s(A, B) = 1$, if and only if $A = B, \forall A, B \in SVNS(X)$.

3. A New Approach in Finding the Best Alternative Among Alternatives

Suppose an expert A_i with weightage W_i comments about the criteria c_i which can be expressed by neutrosophic numbers ${c_i}^{A_i}$. The different criteria given by several experts shown in table as follows.

	C_1	C_2	C_3	...	C_n
A_1	${c_1}^{A_1}$	${c_2}^{A_1}$	${c_3}^{A_1}$	...	${c_n}^{A_1}$
A_2	${c_1}^{A_2}$	${c_2}^{A_2}$	${c_3}^{A_2}$	...	${c_n}^{A_2}$
A_3	${c_1}^{A_3}$	${c_2}^{A_3}$	${c_3}^{A_3}$	...	${c_n}^{A_3}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_m	${c_1}^{A_m}$	${c_2}^{A_m}$	${c_3}^{A_m}$	...	${c_m}^{A_m}$

where each ${c_i}^{A_j}$ is a NS, i.e., ${c_i}^{A_j} = \{T_{ij}, I_{ij}, F_{ij}\}$, $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. The proposed method aims to determine the optimal alternative.

A NS is essentially a vector valued function, mapping each element to a point in 3D space.

First we fix a alternative, Let (T_A^i, I_A^i, F_A^i) is a neutrosophic number corresponding to a point P_i in 3D space. Let weight vector W_i act at the point P_i. Let the components of W_i parallel to the axes are (X_i, Y_i, Z_i) respectively. Hence the component force Z_i at P_i is equivalent to a force Z_i at O along OZ, O is the origin and a couple of moment $I_A^i Z_i$ about OX and a couple of moment $-T_A^i Z_i$. Similarly, the force X_i at P_i is equivalent to a force X_i at O along OX and a couple of moment $F_A^i Z_i$ about OY and a couple of moment $-I_A^i X_i$ about OZ.

Also the component force Y_i at P_i is equivalent to a force Y_i at O along OY and a couple of moment $T_A^i Y_i$ about OZ and a couple of moment $-F_A^i Y_i$ about OX. In this way the three component forces X_i, Y_i, Z_i acting at P_i are equivalent to a force X_i at O along OX, a force Y_i at O along OY, and a force Z_i at O along OZ and a couple of moment $I_A^i Z_i - F_A^i Y_i$ about OX, a couple of moment $F_A^i X_i - T_A^i Z_i$ about OY and a couple of moment $T_A^i Y_i - I_A^i X_i$ about OZ. Hence the system of force is equivalent to a couple of moment $T_{R_j} = \sum_{i=1}^{n} (I_A^i Z_i - F_A^i Y_i)$ about OX, a couple of moment $I_{R_j} = \sum_{i=1}^{n} (F_A^i X_i - T_A^i Z_i)$ about OY and a couple of moment $F_{R_j} = \sum_{i=1}^{n} (T_A^i Y_i - I_A^i X_i)$ about OZ where $j = 1, 2, \ldots, m$.

Now the greater the value of couple of moment T_{R_j} about OX, smaller the stability of occurring any event. The lower the value of couple of moment I_{R_j} about OY, the lower the stability of occurring that event and the lower the value of couple of moment F_{R_j} about OZ, the lower the truthfulness of that event. Now object is to identify the optimal alternative in which stability is maximum. Since in neutrosophic set $(1, 0, 0)$ indicates the complete satisfaction without uncertainty and zero moment indicates that the force has no tendency to rotate, we find the similarity measure S between $(1, 0, 0)$ and $(T_{R_j}, I_{R_j}, F_{R_j})$. Now larger the value of S corresponds to the less stability of event.

3.1. Example

Suppose an expert E gives opinion about occurring of events E_1, E_2 and E_3 by $(0.3, 0.2, 0.3)$, $(0.4, 0.2, 0.3)$ and $(0.2, 0.4, 0.4)$ respectively with weight vector $(0.4, 0.4, 0.2)$. Then how can we measure the stability of his opinion?

We use the proposed method to evaluate the stability. Here $(T_A^1, I_A^1, F_A^1) = (0.3, 0.2, 0.3)$, $(T_A^2, I_A^2, F_A^2) = (0.4, 0.2, 0.3)$, $(T_A^3, I_A^3, F_A^3) = (0.2, 0.4, 0.4)$ and $(X_i, Y_i, Z_i) = (0.4, 0.4, 0.2)$ for $i = 1, 2, 3$. We find out $(T_{R_1}, I_{R_1}, F_{R_1}) = (0.24, 0.255, 0.2)$ by using neutrosophic vector operations given in subsection 2.4. Now similarity measure value between $(1, 0, 0)$ and $(T_{R_1}, I_{R_1}, F_{R_1})$ [using formula 1 from [31]] gives the measurement value 0.548459.

More examples are given in the Table 1, considering weight vector as $(0.4, 0.5, 0.1)$.

Table 1. *Some Examples.*

	Information in NS form	***Similarity measure***
1.	$\{(0.3, 0.2, 0.3), (0.4, 0.2, 0.3), (0.2, 0.4, 0.4)\}$	0.5831
2.	$\{(0.4, 0.2, 0.3), (0.4, 0.2, 0.3), (0.2, 0.4, 0.4)\}$	0.5697
3.	$\{(0.3, 0.3, 0.3), (0.4, 0.2, 0.3), (0.2, 0.4, 0.4)\}$	0.5912
4.	$\{(0.3, 0.2, 0.4), (0.4, 0.2, 0.3), (0.2, 0.4, 0.4)\}$	0.5867
5.	$\{(0.3, 0.2, 0.3), (0.4, 0.2, 0.3), (0.2, 0.4, 0.4)\}$	0.5484

3.2. Sensitivity Analysis

From the examples, it is seen that (comparing examples 1. and 2.) small increment of truth membership gives less similarity measure value, i.e., better stability. Small increment of indeterminacy membership (comparing 1. and 3.)gives larger similarity measure value, i.e., less stability and small increment

of falsity membership (comparing 1. and 4.) gives larger similarity measure value, i.e., also less stability. So, the proposed method is sensitive to little change in a NS and gives clear indication in the change of the stability of the NS.

4. Numerical Example [Adapted from [8]]

Let us consider the decision-making problem adapted from [8]. There is an investment company, which wants to invest a sum of money in the best option. There is a panel with four possible alternatives to invest the money: (1) A_1 is a car company; (2) A_2 is a food company; (3) A_3 is a computer company; (4) A_4 is an arms company. The investment company must take a decision according to the following three criteria: (1) C_1 is the risk; (2) C_2 is the growth; (3) C_3 is the environmental impact. Then, the weight vector of the criteria is given by $W = (0.35, 0.25, 0.4)$. We apply the proposed approach to find the best alternative from the data given in Table 2.

Table 2. Information given by Decision maker([8]).

	A_1	A_2	A_3	A_4
C_1	(0.4,0.2,0.3)	(0.6,0.1,0.2)	(0.3,0.2,0.3)	(0.7,0,0.1)
C_2	(0.4,0.2,0.3)	(0.6,0.1,0.2)	(0.5,0.2,0.3)	(0.6,0.1,0.2)
C_3	(0.2,0.2,0.5)	(0.5,0.2,0.2)	(0.5,0.3,0.2)	(0.4,0.3,0.2)

4.1. Algorithm

Step 1: Consider each neutrosophic data given in the Table 2 as a point in 3D space.

Step 2: Calculate the couple of moment T_{R_j}, I_{R_j}, F_{R_j}, $j = 1, 2, 3, 4$ about x,y and z axis respectively

Step 3: Find the similarity measure S between $(1, 0, 0)$ and $(T_{R_j}, I_{R_j}, F_{R_j})$ using the similarity measure formula 1 from [31]

Step 4: Least value of the similarity measures give the best alternative.

4.2. Result

By Step 2, For the alternative, A_1, $T_{R_1} = 0.055, I_{R_1} = 0.205, F_{R_1} = 0.08$,

For the alternative $A_2, T_{R_2} = 0.05, I_{R_2} = 0.47, F_{R_2} = 0.285$,

For the alternative $A_3, T_{R_3} = 0.08, I_{R_3} = 0.24, F_{R_3} = 0.08$,

For the alternative A_4, $T_{R_4} = 0.105, I_{R_4} = 0.505, F_{R_4} = 0.295$,

By step 3, the similarity measure vales in case of A_1, A_2, A_3, A_4 are $0.5577, 0.37356, 0.54582, 0.36773$ respectively.

By step 4, A_4 is the best alternative.

4.3. Comparison Analysis

Table 3. The results from several strategies of numerical example.

Methods	*ranking order*	*The best alternative*
Ye [2]	$A_4 > A_2 > A_3 > A_1$	A_4
Ye [6]	$A_4 > A_2 > A_3 > A_1$	A_4
Ye [8]	$A_2 > A_4 > A_3 > A_1$	A_2
Yang et al. [12]	$A_4 > A_2 > A_3 > A_1$	A_4
Ye [27] *method*1	$A_4 > A_2 > A_3 > A_1$	A_4
Ye [27] *method*2	$A_2 > A_4 > A_3 > A_1$	A_2
Mandal et al. [25]	$A_4 > A_2 > A_3 > A_1$	A_4
The proposed method	$A_4 > A_2 > A_3 > A_1$	A_4

4.4. Result Discussion

Table 3 demonstrates that the proposed approach produces the same optimal alternative as existing methods [2], [6], [12], [27] (method 1), [31]. The best alternative is A_4. The results yield consistent ranking. Additionally, the vector method is simple, has clear representation and makes complex mathematical problems easier to understand and solve.

5. Conclusion

In the study a DM framework has been illustrated to address DM problems in uncertain and complex environments. Since real world DM often contain inconsistent, incomplete and indeterminate information, conventional DM methods may not always provide satisfactory results. The proposed approach provides a systematic way to represent and process such information and to identity the most suitable alternative among the available choices. It facilitates the representation and comparison of multiple criteria, simplifies complex calculations and provides consistent, reliable and meaningful result.

Abbreviations

NS	Neutrosophic Set
DM	Decision Making
MCDM	Multi Criteria Decision Making
FS	Fuzzy Set

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Author Contributions

Kanika Mandal: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The author confirms that no competing interests or conflicts of interest exist in relation to the present study or its publication.

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