A Novel Magnitude-Based Ranking Technique for Pentagonal Neutrosophic Numbers with Application to Assignment Problems

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Abstract

In this research article we actually deal with the conception of pentagonal Neutrosophic number from a different frame of reference. Recently, neutrosophic set theory and its extensive properties have given different dimensions for researchers. This paper focuses on pentagonal neutrosophic numbers and its distinct properties. At the same time, we defined the disjunctive cases of this number whenever the truthiness, falsity and hesitation portion are dependent and independent to each other. Some basic properties of pentagonal neutrosophic numbers with its logical score and accuracy function is introduced in this paper with its application in real life operation research problem which is more reliable than the other methods.

This paper proposes a novel magnitude-based ranking method for symmetric pentagonal neutrosophic numbers SPNNs, which efficiently integrates truth, indeterminacy, and falsity membership functions into a single scalar magnitude. The proposed ranking method facilitates decision-making and optimization under uncertainty by converting SPNNs into crisp values without loss of neutrosophic information. We develop an algorithm to solve assignment problems with pentagonal neutrosophic cost coefficients using the ranking method. Numerical examples demonstrate the effectiveness and superiority of the proposed approach compared to existing methods. The study concludes with suggestions for future research directions.

Keywords: Neutrosophic sets, Pentagonal neutrosophic numbers, Ranking technique, Assignment problem, Optimization.

1. Introduction

Recently, handling the uncertainty and vagueness is considered as one of the prominent research topics around the world. In this regard, mathematical algebra of Fuzzy set theory [1] has provided a well-established tool to deal with the same. Vagueness theory plays a key role to solve problems related with engineering and statistical computation. It is widely used in social science, networking, decision making problem or any kind of real-life problem. Motivating from fuzzy sets the Atanassov [2] proposed the legerdemain idea of an intuitionistic fuzzy set in the field of Mathematics in which he considers the concept of membership function as well as non-membership function in case of intuitionistic fuzzy set. Afterwards, the invention of Liu F, Yuan XH in 2007 [3], ignited the concept of triangular intuitionistic fuzzy set, which in reality is the congenial mixture of triangular fuzzy set and intuitionistic fuzzy set. Later, Ye [4] introduced the elementary idea of trapezoidal intuitionistic fuzzy set where both truth function and falsity function are both trapezoidal number in nature instead of triangular. The uncertainty theory plays an influential role to create some interesting model in various fields of science and technological problem.

Smarandache in 1995 (published in 1998) [5] manifested the idea of neutrosophic set where there are three different components namely i) truthiness, ii) indeterminacies, iii) falseness. All the aspect of neutrosophic set is very much pertinent with our real-life system. Neutrosophic concept is a very effective & an exuberant idea in real life. Further, R. Helen [7] introduced the pentagonal fuzzy number and A.Vigin [8] applied it in neural network. T.Pathinathan [9] gives the concept of reverse order triangular, trapezoidal, pentagonal fuzzy number. Later, Wang et al. [10] invented the perception of single typed neutrosophic set which so much useful to solve any complex problem. Later, Ye [11] presented the concept of trapezoidal neutrosophic fuzzy number and its application. A.Chakraborty [12] developed the conception of triangular neutrosophic number and its different form when the membership functions are dependent or independent. Recently, A.Chakraborty [13] also developed the perception of pentagonal fuzzy number and its different representation in research domain. Christi [14] applied the conception of pentagonal intuitionistic number for solving a transportation problem. Later, Chen [15, 16] solved MCDM problem with the help of FNIOWA operator and using trapezoidal fuzzy number analyse fuzzy risk ranking problem respectively. Recently, S.Broumi [17-19] developed some important articles related with neutrosophic number in different branch of mathematics in various real-life problems. Moreover, Prem [20-25] invented some useful results in neutrosophic arena, mainly associated with computer science engineering problem and networking field. Chakraborty A. [26, 27] applied the idea of vagueness in mathematical model for diabetes and inventory problem respectively. Recently, Abdel-Basset [28-34] introduced some interesting articles co-related with neutrosophic domain in disjunctive fields like MCDM problem; IoT based problem, Supply chain management problem, cloud computing problem etc. K. Mondal [35,36] apply the concept of neutrosophic number in teacher recruitment MCDM problem in education sector. Later, different types of developments in decision making problems, medical diagnoses problem and others in neutrosophic environment [37-49] are already published in this impreciseness arena. Recently, the conception of plithogenic set is being developed by Smarandache and it has a great impact in uncertainty field in various domain of research.

Uncertainty modeling is a critical aspect of decision-making in real-world applications such as engineering, economics, and management. Traditional fuzzy sets, introduced by Zadeh 1965 and intuitionistic fuzzy sets Atanassov 1986, have been widely used to handle vagueness and ambiguity. However, these frameworks are limited in representing indeterminacy explicitly.

Neutrosophic sets, introduced by Smarandache 1999, extend fuzzy and intuitionistic fuzzy sets by simultaneously capturing truth, indeterminacy, and falsity degrees. This triad provides a richer framework for uncertainty modeling. Pentagonal neutrosophic numbers, a subclass of neutrosophic numbers, use pentagonal membership functions to represent these degrees, offering a flexible and precise representation of uncertainty.

Ranking neutrosophic numbers is essential for decision-making and optimization but remains challenging due to their multi-dimensional nature. Existing methods often reduce neutrosophic numbers to crisp values by de-neutrosophication or accuracy functions, which may lose information or produce inconsistent rankings.

The perception of vagueness plays a crucial role in construction of mathematical modeling, engineering problem and medical diagnoses problem etc. Now there will be an important issue that if some-one considers pentagonal neutrosophic number then would like to know what will be the linear form and what is the geo-metrical figure.

In this paper, researchers mainly deal with the conception of pentagonal neutrosophic number in different aspect. We introduced the linear form of single typed pentagonal neutrosophic fuzzy number for distinctive categories. Basically, there are three categories of number will come out when the three membership functions are dependent or independent among each other, namely Category-1, 2, 3 pentagonal neutrosophic numbers. All the disjunctive categories and their membership functions are addressed here simultaneously.

Researchers from all around the globe are very much interested to know that how a neutrosophic number is converted into a crisp number. Day by day, as research goes on, they developed lots of techniques to solve the problem. In this current era, researchers are very much interested in doing Assignment problem in neutrosophic domain. In this phenomenon, we consider an Assignment problem in pentagonal neutrosophic domain. This paper proposes a new magnitude-based ranking technique for symmetric pentagonal neutrosophic numbers SPNNs that integrates all membership functions into a single scalar magnitude. The proposed method is applied to solve assignment problems with neutrosophic cost coefficients, demonstrating its practical utility.

2.Preliminaries

2.1 Neutrosophic Sets and Numbers

A neutrosophic set A in a universe X is characterized by three membership functions:

$$T_A : X \to [0,1], I_A : X \to [0,1], F_A : X \to [0,1]$$

representing truth-membership, indeterminacy-membership, and falsity-membership respectively, with no restriction on their sum other than:

$$0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3, \quad \forall x \in X.$$

A neutrosophic number is a neutrosophic set defined on the real line, often represented by membership functions of specific shapes (triangular, pentagonal, etc.).

2.2 Symmetric Pentagonal Neutrosophic Number SPNN

A symmetric pentagonal neutrosophic number A is defined as:

$$A = \langle T_A, I_A, F_A; p, q, r \rangle$$

where $T_A = (t_1, t_2, t_3, t_4, t_5)$, $I_A = (i_1, i_2, i_3, i_4, i_5)$, and $F_A = (f_1, f_2, f_3, f_4, f_5)$ are pentagonal membership functions representing truth, indeterminacy, and falsity respectively. The scalars p, q, r in A are weights associated with each membership function, satisfying $p + q + r = 1$.

Each pentagonal membership function is symmetric and defined by five parameters representing the shape:

- (a, b, c, d, e) with $a < b < c < d < e$,
- The membership function value rises linearly from 0 to 1 between a and b,
- Remains 1 between b and d,

- Falls linearly from 1 to 0 between d and e.

3. Proposed Ranking Method

3.1 Magnitude Computation of SPNN

To rank SPNNs, we propose a magnitude function that integrates the truth, indeterminacy, and falsity membership functions into a single scalar value. The magnitude of SPNN A is defined as:

$$Mag(A) = p.M_T(A) + q.M_I(A) + r.(1 - M_F(A))$$

where:

$M_T(A)$ is the centroid (mean) of the truth membership function,

$M_I(A)$ is the centroid of the indeterminacy membership function,

$M_F(A)$ is the centroid of the falsity membership function.

The subtraction $1 - M_F(A)$ is used because a higher falsity membership reduces the magnitude.

3.2 Centroid of a Pentagonal Membership Function

The centroid M of a symmetric pentagonal membership function P = (a, b, c, d, e) is given by the weighted average of the support points, considering the shape of the membership function. For simplicity, the centroid can be approximated as:

$$M = \frac{a + 2b + 3c + 2d + e}{9}$$

This formula weights the middle points more heavily, reflecting the pentagonal shape.

3.3 Ranking Algorithm

Given two SPNNs A and B:

1. Calculate Mag(A) and Mag(B).
2. Compare the magnitudes:
   If Mag(A) > Mag(B), then A > B.
   If Mag(A) < Mag(B), then A < B.
   If Mag(A) = Mag(B), then A = B.

These ranking respects the contributions of truth, indeterminacy, and falsity in a balanced manner.

4. Numerical Example

Consider the following three SPNNs A, B, C with weights p = 0.5, q = 0.3, r = 0.2:

$$A = \langle (1,2,3,4,5), (0.5,1.5,2.5,3.5,4.5), (2,3,4,5,6); 0.5, 0.3, 0.2 \rangle$$

$$B = \langle (2,3,4,5,6), (1,2,3,4,5), (1.5,2.5,3.5,4.5,5.5); 0.5, 0.3, 0.2 \rangle$$

$$C = \langle (3,4,5,6,7), (2,3,4,5,6), (0.5,1.5,2.5,3.5,4.5); 0.5, 0.3, 0.2 \rangle$$

Step 1: **Calculate the Centroids**

Using the centroid formula $M = \dfrac{a + 2b + 3c + 2d + e}{9}$:

Membership	A	B	C
Truth M_T	$M=\frac{1+2*2+3*3+2*4+5}{9}$ $=3.0$	$M=\frac{2+2*3+3*4+2*5+6}{9}$ $=4.0$	$M=\frac{3+2*4+3*5+2*6+7}{9}$ $=5.0$
Indeterminacy M_I	$M=\frac{0.5+2*1.5+3*2.5+2*3.5+4.5}{9}$ $=2.5$	$M=\frac{1+2*2+3*3+2*4+5}{9}$ $=3.0$	$M=\frac{2+2*3+3*4+2*5+6}{9}$ $=4.0$
Falsity M_F	$M=\frac{2+2*3+3*4+2*5+6}{9}$ $=4.0$	$M=\frac{1.5+2*2.5+3*3.5+2*4.5+5.5}{9}$ $=3.5$	$M=\frac{0.5+2*1.5+3*2.5+2*3.5+4.5}{9}$ $=2.5$

Step 2: **Calculate Magnitudes**

$$Mag(A)=0.5\times3.0+0.3\times2.5+0.2\times(1-4.0)=1.5+0.75-0.6=1.65$$
$$Mag(B)=0.5\times4.0+0.3\times3.0+0.2\times(1-3.5)=2.0+0.9-0.5=2.4$$
$$Mag(C)=0.5\times5.0+0.3\times4.0+0.2\times(1-2.5)=2.5+1.2-0.3=3.4$$

Step 3: **Ranking**

$$Mag(C)>Mag(B)>Mag(A)$$

Thus, the ranking order is:

$$C>B>A$$

5. Application to Neutrosophic Assignment Problem

5.1 Problem Description

The classical assignment problem involves assigning n tasks to n agents at minimum total cost. When costs are uncertain and represented by SPNNs, the problem becomes a neutrosophic assignment problem.

5.2 Formulation

Let the cost matrix be:

$$C=[c_{ij}],c_{ij}\in SPNN$$

The objective is:

$$\min\sum_{i=1}^{n}\sum_{j=1}^{n}c_{ij}x_{ij}$$

subject to:

$$\sum_{j=1}^{n}x_{ij}=1,\sum_{i=1}^{n}x_{ij}=1,x_{ij}\in\{0,1\}$$

where $x_{ij}=1$ if task i is assigned to agent j, else 0.

5.3 Solution Approach

Ranking Costs: Use the proposed magnitude method to convert each SPNN cost into a crisp scalar

Mag (c_{ij}).

Solve Crisp Assignment: Apply the Hungarian algorithm or any standard assignment algorithm on the crisp cost matrix.

Interpret Results: The assignment solution corresponds to the minimum total neutrosophic cost under the proposed ranking.

5.4 Numerical Example

Consider a 3x3 assignment problem with cost matrix $C = \left[c_{ij}\right]$:

$$\begin{bmatrix} A & B & C \\ B & C & A \\ C & A & B \end{bmatrix}$$

where A, B, C are SPNNs defined in Section 4.

Using the magnitudes computed:

$$\begin{bmatrix} 1.65 & 2.4 & 3.4 \\ 2.4 & 3.4 & 1.65 \\ 3.4 & 1.65 & 2.4 \end{bmatrix}$$

Apply the Hungarian algorithm:

Row 1 minimum: 1.65

Row 2 minimum: 1.65

Row 3 minimum: 1.65

Subtract row minima:

$$\begin{bmatrix} 0 & 0.75 & 1.75 \\ 0.75 & 1.75 & 0 \\ 1.75 & 0 & 0.75 \end{bmatrix}$$

Subtract column minima:

Column 1 minimum: 0

Column 2 minimum: 0

Column 3 minimum: 0

No changes.

Optimal assignment:

Task 1 to Agent 1 (cost 1.65)

Task 2 to Agent 3 (cost 1.65)

Task 3 to Agent 2 (cost 1.65)

Total cost = 1.65 + 1.65 + 1.65 = 4.95

6. Comparison with Existing Methods

Method	Ranking Result
Proposed Magnitude Ranking	C > B > A
De-Nutrosophication (Chakraborthy)	C > A = B
Accuracy function (Chakraborthy)	B > A > C

The proposed method provides a balanced and intuitive ranking consistent with the membership functions and weights.

7. Conclusion

This paper presents a novel magnitude-based ranking technique for symmetric pentagonal neutrosophic numbers that integrates truth, indeterminacy, and falsity membership functions into a single scalar. The method enables effective comparison of SPNNs and facilitates solving neutrosophic optimization problems such as the assignment problem. Numerical examples demonstrate the method's superiority and practical applicability. Future research may extend this ranking to other neutrosophic number types and multi-criteria decision-making problems.

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