Neutrosophic Sets and Systems, Vol. 96, 2026
University of New Mexico

Enhancing Transportation Problem Solutions Using A New Ranking Function In a Neutrosophic Environment

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Abstract: Transportation problems often involve uncertainties in cost, supply, and demand, which traditional optimisation methods struggle to handle effectively. Neutrosophic numbers can handle such uncertainties and incomplete information. This paper introduces a new ranking function for solving transportation problems in a neutrosophic environment, which provides a better framework for addressing indeterminate, vague, and inconsistent information. By integrating neutrosophic sets and their arithmetic operations, this study offers a computationally efficient approach to transforming crisp problems into a solvable format. Numerical examples and comparative analysis demonstrate the effectiveness of the proposed ranking function.

Keywords: Transportation problem, neutrosophic number, ranking function, indeterminacy.

1. Introduction

In today's world, many problems involve various forms of uncertainty that cannot be effectively addressed using classical mathematical theories. To handle situations involving vague or imprecise information, Zadeh [1] introduced fuzzy set theory in 1965, which is defined by membership values. However, in several cases, decisions or results derived from the available data lack the desired level of precision. To address these limitations, advanced forms of fuzzy sets have been proposed. Among them, the intuitionistic fuzzy set, introduced by Atanassov [2] in 1986, became notable for handling imprecise information using both membership and non-membership values [3]. Consequently, both fuzzy and intuitionistic fuzzy set theories have been widely applied in real-world decision-making problems. Over time, it was observed that generalisations of fuzzy sets still struggled to address issues involving indeterminate or inconsistent information. To bridge this gap, Smarandache [4]introduced neutrosophic sets in 1998 as a further extension of classical, fuzzy, and intuitionistic fuzzy sets. Neutrosophic sets incorporate three components: truth-membership, indeterminacy-membership, and falsity-membership degrees, making them well-suited for representing uncertainty and inconsistency. Wang et al. [5]. later applied the concept of single-valued neutrosophic sets to various practical problems. The study of optimal transportation models in a cost-effective manner has played a significant role in the field of supply chain management. Numerous researchers [6], [7], have developed mathematical formulations of transportation problems under various environmental conditions. The classical transportation problem was first stated by Hitchcock [8], in 1941, in which the transportation problem was formulated using precise, or *crisp*, values for its constraints. However, in today's dynamic environment, transportation parameters such as demand, supply, and unit transportation cost are often uncertain due to various uncontrollable factors. To address these uncertainties, many researchers have developed and solved fuzzy transportation models. Out of these, Ó hÉigeartaigh [9] developed one of the earliest fuzzy transportation algorithms, incorporating fuzzy costs into classical transportation models. Chanas and Kuchta [10]. Introduced a structured approach to identify optimal solutions in transportation problems with fuzzy cost coefficients. Some researchers contributed significantly to solving fuzzy solid transportation problems by applying and enhancing evolutionary algorithms, including genetic and parametric approaches [11] [12], [12], [13]. Adamo [14] introduced the concept of α-preference, a method for ranking fuzzy numbers based on the α-level sets, providing a practical approach for decision-making scenarios. Yager [15] proposed several indices for ranking fuzzy subsets, focusing on the development of measures that could effectively capture the preference ordering among fuzzy numbers. Dubois and Prade [16]**,** they introduced dominance-based ranking methods and explored the use of possibility theory for comparing fuzzy quantities, contributing significantly to the theoretical foundation of fuzzy rankings. Giovanni Bortolan and R. Degani [17] conducted a comprehensive review of various methods for ranking fuzzy subsets, including approaches by Yager, Adamo, and Dubois & Prade. Their work highlighted the importance of ranking in decision-making processes involving fuzzy numbers. Some researchers significantly advanced decision-making and transportation models by introducing similarity measures, ranking methods, and heuristics under single-valued neutrosophic and trapezoidal neutrosophic environments[18, 19, 20, 21].Selvakumari [22]. Introduced a novel approach to neutrosophic transportation problems using the Zero Suffix Method, demonstrating its effectiveness in handling indeterminate and inconsistent data through a simplified algorithmic structure.

Umamageswari R. M. & G. Uthra[23]. This duo proposed a weighted average ranking method designed explicitly for generalised single-valued neutrosophic trapezoidal numbers, applying it effectively to transportation problems under uncertainty.

Expanding upon the framework of neutrosophic logic, Saini et al.[24], explored the application of single-valued trapezoidal neutrosophic numbers to model uncertainties in cost parameters. Their study illustrated how neutrosophic sets could enhance the decision-making capabilities of transportation models when crisp values are inadequate to express the true nature of logistical data.

Similarly, Rabinson and Rajendran [25], utilised decagonal neutrosophic numbers in transportation problems, offering a fresh numerical representation to capture finer gradations of truth, indeterminacy, and falsity. Their methodology emphasised precision in modelling complex logistics environments.
To further address the ambiguity present in transportation systems, Hemalatha et al.[26], proposed a solution for the type-II neutrosophic fuzzy transportation problem, combining both neutrosophic and fuzzy environments. This hybrid model was shown to represent better situations where decision-makers face both hesitant and indeterminate information.
Building on these advancements, Karak et al.[27]. Developed a comprehensive solution technique for the transportation problem in a general neutrosophic environment, formulating new operational rules and optimisation strategies that enhance solution reliability under various uncertain conditions. Kalaivani Kaspar & Palanivel Kaliyaperumal [28] Introduced a novel ranking function tailored for single-valued trapezoidal neutrosophic numbers (SVTNNs) to address transportation problems with mixed constraints, enhancing the accuracy of optimal solutions. N. Parveen, K. Prabu & V. Sangeetha [29], developed a new ranking function for heptagonal intuitionistic fuzzy numbers and applied it to solve transportation problems, demonstrating improved decision-making under uncertainty. Balasundaram Baranidharan & Ghanshaym Singha Mahapatra [30]. Introduced an alpha-cut-based ranking technique for heptagonal fuzzy numbers, formulating the Generalised Ranking Heptagonal Fuzzy Method (GRHFM) to solve regional shipment transportation problems. Kaspar and Kaliyaperumal [31] tackled the transportation problem under mixed constraints by applying single-valued trapezoidal neutrosophic numbers, thus accommodating multiple types of real-life constraints within the neutrosophic framework[32]. Their contribution is notable for expanding the applicability of neutrosophic transportation models to more generalised and practical scenarios.[33].

The incorporation of neutrosophic sets in this research significantly enhances the modeling and analysis of uncertainty, imprecision, and incomplete information inherent in real-world problems. Traditional methods often fail to effectively handle ambiguous or inconsistent data, whereas the neutrosophic sets provide a more flexible and robust framework by considering truth, indeterminacy, and falsity simultaneously. The neutrosophic numbers considered in this work is able to handle the vagueness in much better way compared to other extensions of fuzzy numbers. Here the transportation problems are solved where the parameters like cost, demand, supply etc. are all the neutrosophic in nature, in which the indeterminacy is converted into crisp by using a new proposed ranking function with yields the better, optimized cost for the transportation problems. Numericals have been discussed to validate the proposed Ranking function.

Table 1. List of abbreviations

TP	Transportation problem
NN	Neutrosophic number
NTP	Neutrosophic transportation problem
CNTP	Crisp neutrosophic transportation problem
SVNN,	Single-valued neutrosophic number
SVPNN,	Single-valued pentagonal neutrosophic number
SVONN	Single-valued octagonal neutrosophic number

2. Preliminaries

2.1 Neutrosophic Sets and numbers.

2.1.1 Definition (Neutrosophic set)

Three membership functions define a neutrosophic set:
Truth Membership (T): The degree to which an element belongs to a set.
Indeterminacy Membership (I): Degree of uncertainty in classification.
Falsity Membership (F): Degree to which an element does not belong to the set.
These elements are mathematically represented as:

$$NS = \{(x, T(x), I(x), F(x)) \ / \ x \in X\}$$

2.1.2 Definition: (Classical)

Let X be a non-empty set. Then an NS $\tilde{A}^N$ on X defined as

$$\tilde{A}^N=\{\langle x, T_{\tilde{A}^N}(x), I_{\tilde{A}^N}(x), F_{\tilde{A}^N}(x)\rangle / x \in X\},$$

Where $T_{\tilde{A}^N}(x), I_{\tilde{A}^N}(x), F_{\tilde{A}^N}(x)$ Are the truth membership function, the indeterminacy function, and the falsity function.

2.1.3 Definition: (Neutrosophic number) [27]

A neutrosophic number represented by $z = x + yI$ for $x, y \in R$, where x is the determinate part and yI Is the indeterminate part. Here $I \in [I_l, I_u]$ where I_l and I_u Stands for lower and upper indeterminacy.

When $I = 0$ (No indeterminacy) z is a real crisp value.

2.2 Arithmetic Operations on Neutrosophic Numbers

Neutrosophic numbers (NNs) follow specific arithmetic rules,

Consider $z_1 = x_1 + y_1 I$ and $z_2 = x_2 + y_2 I$

$z_1 \pm z_2$=$x_1 \pm x_2$+$(y_1 \pm y_2)I$.

$z_1 \times z_2$=$x_1 x_2$+$(x_1 y_2 + x_2 y_1$+$y_1 y_2)I$

$0.I$=0

$z_1{}^2 = (x_1 + y_1 I)^2 = x_1{}^2 + (2x_1 y_1$+$y_1{}^2)$

$I^n = I \ (n \geq 1)$

$$\frac{I}{I} = \text{undefined}$$

Remark 1: For any NN $z = x + yI$ and $I \in [I_l, I_u]$ the NN gets converted into an interval form $[x + yI_l, x + yI_u]$=$[c_l, c_u]$.

For example: For a NN $z = 13 + 5I$ where $I = [0,0.5]$ then z is equivalent to [13, 15.5]

3. Proposed Ranking Function and Ranking Rules

3.1 Definition (Ranking Function)

Let $\bar{C} = c + c'I$ Be a NN. For $I \in [I_l, I_u]$, $\bar{C}$ can be converted into an interval form $[c_l, c_u]$. The ranking function is defined as

$$R(\bar{C}) = R(c + c'I) = R([c_l, c_u]) = \frac{2}{\left[\frac{1}{c_l} + \frac{1}{c_u}\right]} \quad (1)$$

3.1.1 Significance of Proposed Ranking Function:

The ranking function in this work is used purely as a defuzzification tool to convert fuzzy parameters into crisp values, enabling the application of classical optimisation methods. It plays a crucial role in making the fuzzy model computationally feasible while retaining the uncertainty representation of the original data.

3.1.2 Ranking Rules for the proposed ranking function:

Here $\bar{P} = p + p'I$ and $\bar{Q} = q + q'I$ be two NNS. Then for $I \in [I_l, I_u]$ we have,

If $(\bar{P}) \leq R(\bar{Q})$, then $\bar{P} \leq_N \bar{Q}$

If $(\bar{P}) \geq R(\bar{Q})$, then $\bar{P} \geq_N \bar{Q}$

If $(\bar{P}) = R(\bar{Q})$, then $\bar{P} =_N \bar{Q}$

For example, consider two NNs, $\bar{P} = 9 + 5I$ and $\bar{Q} = 3 + 4I \; for \; I \in [0,0.3]$

$$R(9 + 5I) = R([9,10.5]) = 9.7$$
$$R(3 + 4I) = R([3,4.2]) = 3.5$$
$$\therefore R(9 + 5I) \geq R(3 + 4I) \Longrightarrow 9 + 5I \geq 3 + 4I$$

3.2. Neutrosophic Transportation Problem

3.2.1 Formulation of Model

The NTP can be formulated with $\mathcal{S}$ supply points and $\mathcal{D}$ Destination points as follows:

$$\min z = \sum_{i=1}^{\mathcal{S}} \sum_{j=1}^{\mathcal{D}} \bar{\mathcal{T}}_{ij} \bar{X}_{ij}$$

Subject to the constraints,

$$\sum_{j=1}^{\mathcal{D}} X_{ij} = \bar{s}_i \quad \forall \, i = 1,2, \dots \dots, \mathcal{S}$$
$$\sum_{i=1}^{\mathcal{S}} X_{ij} = \bar{d}_j \quad \forall \, j = 1,2, \dots \dots, \mathcal{D} \quad (2)$$

Here $\bar{\mathcal{T}}_{ij} = t_{ij} + t'_{ij}I$ denotes the neutrosophic transportation cost of delivering a single unit from the i^{th} supply point to the j^{th} Destination point.

In the constraints, $\bar{s}_i = s_i + s'_i I$ represents the neutrosophic supply at the i^{th} supply point and $\bar{d}_j = d_j + d'_j I$ denotes neutrosophic demand at the j^{th} Destination point.
The objective is to determine the quantity. $X_{ij}(\geq 0)$ to be allocated at each $(i,j)^{th}$ Location such that the total transportation cost is minimised.

3.2.2 Solution Procedure

The methodology for solving the NTP is presented through the following stepwise procedure:
Step 1: Transforming the given NTP into an interval TP by taking a suitable value of $I \in [I_l, I_u]$ $(see\ Remark\ 1)$.
The mathematical formulation is

$$\min z = \sum_{i=1}^{\mathcal{S}} \sum_{j=1}^{\mathcal{D}} [\bar{\mathcal{T}}_{ijl}, \bar{\mathcal{T}}_{iju}] X_{ij}$$

Subject to constraints,

$\sum_{j=1}^{\mathcal{D}} X_{ij} = [s_{il}, s_{iu}] \quad \forall\, i = 1,2, \dots \dots, \mathcal{S}$ (3)

$\sum_{i=1}^{\mathcal{S}} X_{ij} = [d_{jl}, d_{ju}] \quad \forall\, j = 1,2, \dots \dots, \mathcal{D}$

Step 2: Apply the proposed ranking function $R([c_l, c_u])$ On the above obtained intervals.
The NTP is transformed into a Crisp Neutrosophic Transportation Problem (CNTP), characterised by crisp supply, demand, and cost parameters, expressed as follows:

$$\min z = \sum_{i=1}^{\mathcal{S}} \sum_{j=1}^{\mathcal{D}} R([\bar{\mathcal{T}}_{ijl}, \bar{\mathcal{T}}_{iju}]) X_{ij}$$

s.t

$\sum_{j=1}^{\mathcal{D}} X_{ij} = R([s_{il}, s_{iu}]) \quad \forall\, i = 1,2, \dots \dots, \mathcal{S}$

$\sum_{i=1}^{\mathcal{S}} X_{ij} = R([d_{jl}, d_{ju}]) \quad \forall\, j = 1,2, \dots \dots, \mathcal{D}$ (4)

Step 3: Solve the CNTP using any standard method to obtain the values of X_{ij}
Step 4: Allocate these X_{ij} Values are used in the objective function to compute the minimum transportation cost.

3.3 Model Testing and Results

We illustrate the approach by solving. 4×5 and 3×4 NTP for two different values of I. In the first case, we consider $I \in [0,0.6]$ and in the second step, we first consider a crisp problem, then for fuzzification we take $I \in [0,1]$.

Example -1

Consider a garment manufacturing company with production centers located in Mumbai, Pune, Kolhapur, and Goa. The garments produced at these centers are distributed to Chennai, Bengaluru, Hyderabad, Nagpur, and Jaipur.
NOTE: In this 4×5 NTP, the neutrosophic cost, supply, and demand parameters are presented in the following table.

Table 2. Transportation Problem Incorporating Neuromorphic Cost Coefficients

	Chennai	Bengaluru	Hyderabad	Nagpur	Jaipur	Source
Mumbai	4+6I	3+4 I	2+4 I	6+6 I	2+2 I	7+4 I
Pune	7+4 I	17+ I	6+3 I	2+3 I	4+5 I	10+3 I
Kolhapur	11+4 I	8+2 I	9+2 I	7+4 I	12+2 I	8+3 I
Goa	4+ 5I	5+2 I	10+3 I	15+4 I	11+4 I	5+2 I
Demand	8+2 I	4+ 4I	6+ 2I	9+3 I	3+I	

A balanced transportation problem is considered, where the total supply equals the total demand (=30+12 I)

Step 1: Taking $I \in [0,0.6]$, we have converted the above TP into an interval TP using conversion formula (Remark 1) given by the following table

Table 3. TP with Interval-Valued Cost Coefficients

	Chennai	Bengaluru	Hyderabad	Nagpur	Jaipur	Source
Mumbai	[4,7.6]	[3,5.4]	[2,4.4]	[6,9.6]	[2,3.2]	[7,9.4]
Pune	[7,9.4]	[17,17.6]	[9,10.8]	[7,9.4]	[12,13.2]	[10,11.8]
Kolhapur	[11,13.4]	[8,9.2]	[9,10.2]	[7,9.4]	[12,13.2]	[8,9.8]
Goa	[4,7]	[5,6.2]	[10,11.8]	[15,17.4]	[11,13.4]	[5,6.2]
Demand	[8,9.2]	[4,6.4]	[6,7.2]	[9,10.8]	[3,3.6]	

Step 2: The ranking function $R([c_l, c_u]) = \frac{2}{\left[\frac{1}{c_l}+\frac{1}{c_u}\right]}$ is now applied to each of the above intervals.

This leads the TP which will now have the crisp supply, demand and cost parameters as shown in the following table

Table 4. Transportation problem with crisp cost coefficients

	Chennai	Bengaluru	Hyderabad	Nagpur	Jaipur	Source
Mumbai	5.2	3.9	2.8	7.4	2.5	8
Pune	8	17.3	9.8	8	12.6	10.8
Kolhapur	12.1	8.6	9.6	8	12.6	8.8
Goa	5.1	5.5	10.8	16.1	12.1	5.5
Demand	8.6	4.9	6.5	9.8	3.3	

Note: Here also total supply = total demand = 33.1

Step 3: The optimized transportation cost obtained using Vogel's approximation method is

Rs 220.69

3.3.2 Comparative Analysis

Table 5. Comparative result of Proposed Method with Existing Literature

METHOD	TRANSPORTATION COST (in Rs.)
Singh, A. (2024)	230.84
Proposed Method	220.69

The final optimized cost obtained is compared with cost reported in the above-mentioned paper. The proposed method achieves a lower cost.

Example -2

A sample transportation problem is considered with three suppliers and four demand points. The cost matrix, supply, and demand are given in the table below:

Table 6. Crisp transportation table

Distribution Centre						Supply
		D_1	D_2	D_3	D_4	
Plant	P_1	3	1	7	4	300
	P_2	2	6	5	9	400
	P_3	8	3	3	2	500
Demand		250	350	400	200	1200

Step 1: Converting the Crisp problem transportation into NTP

Table 7. Transformation of the Crisp problem into the Neutrosophic Framework

Distribution Centre						Supply
		D_1	D_2	D_3	D_4	
Plant	P_1	2.5+I	0.5+I	6+3I	3.5+2I	280+30I
	P_2	1.5+I	5.5+2I	4.5+I	9+2I	390+20I
	P_3	7.5+2I	2.5+I	2.5+I	1.5+I	490+20I
Demand		245+10I	345+15I	390+20I	390+20I	1160+70I

Step 2: Converting into Interval TP using Remark 1, taking $I = [0,1]$

Table 8. Transformed form of Neutrosophic number $\boldsymbol{c + c'I}$ into interval form $[\boldsymbol{c_l, c_u}]$

Distribution Centre						Supply
		D_1	D_2	D_3	D_4	
Plant	P_1	[2.5,3.5]	[0.5,2.5]	[6,9]	[3.5,5.5]	[280,310]
	P_2	[1.5,2.5]	[5.5,7.5]	[4.5,5.5]	[9,11]	[390,410
	P_3	[7.5,9.5]	[2.5,3.5]	[2.5,3.5]	[1.5,2.5]	[490,510]
Demand		[245,255]	[345,360]	[390,410]	[180,205]	

Step 3: Converting Interval TP into Crisp TP using the proposed Ranking Function.

Table 9. Transformed form of interval form $[\boldsymbol{c_l, c_u}]$ into single crisp value

Distribution Centre						Supply
		D_1	D_2	D_3	D_4	
Plant	P_1	2.9	0.8	7.2	4.3	294.2
	P_2	1.9	6.3	5	10	400
	P_3	8.4	3	3	1.9	500
Demand		250	352	400	192	1194.2

These numbers have been solved using the Least cost method as well as Vogel's method. The results and their comparison with a numerical solution using actual crisp values are shown in the Table below.

3.3.4 Comparative Analysis with Standard Methods.

Table 10. Final optimised transportation cost

METHOD	Transportation Cost by Proposed Ranking Function	Transportation cost With the Actual crisp value
Least Cost Method	2824.4	2850
Vogel's Method	2749	2850

When compared with traditional values and solution techniques, the use of proposed ranking function yields a lower transportation cost, confirming its practical advantage in solving fuzzy transportation problems.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

4. Conclusions

In real-world applications, parameters like supply, demand, and cost are inherently uncertain and cannot always be described using exact numerical values. To manage this ambiguity, fuzzy sets and their various extensions have been widely utilized. Over the years, different techniques have been introduced to defuzzify these uncertain values and convert them into precise figures. In this study, transportation problem parameters are expressed through neutrosophic numbers (NNs), which are then transformed into crisp values using a new developed ranking function. Numerical examples were used to validate the proposed approach. Results showed improved accuracy and reduced computational effort compared to existing ranking methods.

The proposed ranking function simplifies the transformation of neutrosophic numbers into crisp equivalents for computational ease. Unlike previous methods, it offers lower computational complexity, better accuracy in handling vagueness, and applicability to real-life transportation problems.

As an extension of the present work, alternative formulations can be considered, such as cases where only the transportation costs are represented by neutrosophic numbers (NNs) or where only the supply and demand parameters are modelled using NNs. Additionally, instead of focusing solely on balanced neutrosophic transportation problems (NTP), future studies can explore unbalanced neutrosophic transportation problem extensions (NTPE).

Funding: This research received no external funding.

Acknowledgements: In this section, you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: The authors declare no conflict of interest.

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Received: July 26, 2025. Accepted: Sep 9, 2025