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Research Article

Optimizing neutrosophic fractional transportation problem using neutrosophic aspirational approach

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ABSTRACT

The transportation problem is significant in real-life scenarios as it can be utilized in diverse practical applications across various industries and sectors. This problem becomes a fractional transportation problem when the ratio of objective functions is maximized or minimized simultaneously. Real-life problems are often imprecise due to some unpredictable factors like road conditions, weather, price variations and so on. The fuzzy set and intuitionistic fuzzy set are useful for dealing the impreciseness, but there exist some hesitations. To overcome such hesitancy of occurrence and non-occurrence in fuzzy and intuitionistic fuzzy, neutrosophic set is very important and suitable to apply for real life problems. For that reason, in this paper to handle the uncertain, unpredictable and insufficient information in the fractional transportation problem we consider all the parameters as single valued trapezoidal neutrosophic numbers. First, convert the neutrosophic problem into its deterministic problem using the weighted possibility mean. During shipment, sometimes the roles of objective functions and constraints in the problem are not predetermined but may need to be adjusted based on factors such as regulatory changes, market conditions, resource availability, customer priorities and so on. These adjustments contribute to better decision-making, increased cost-effectiveness and improved service efficiency in problems. In this point of view, we have proposed the approach namely, neutrosophic aspirational approach to transform the objective functions of deterministic problem into constraints which is a only novelty of this study. The reduced problem is solved using LINGO software to obtain the optimal compromise solution which is the primary focus of this paper. When the decision makers are in need to select the windmill fans, one may prefer more cost-efficient but less efficient in long-term energy generation while another might have a higher initial cost but offer better long-term benefits. In this situation, the optimal compromise solution obtained by the proposed approach provides valuable insights for the decision makers with flexibility to select their preferred windmill fans using the optimal compromise solution from the available choices based on their financial support. Finally, a sensitivity analysis is performed in the optimal allotment to determine the sensitivity ranges for all the constraints of the problem. Two numerical examples are provided and the comparison was made with the existing approaches available in the literature. It is observed that the obtained optimal compromise solution extracted from the proposed approach provides almost the same result as the existing approaches.

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INTRODUCTION

The transportation problem (TP) is one of the well-known concepts of operations research. The main aim of TP is to optimize the objective function by shipping the products from various sources to different destinations. TP was introduced by Hitchcock [1] in 1941. In 1947, Koopmans [2] developed the procedure for determining the optimal solution. Fractional TP (FTP) is the generalization of TP used for optimization (maximization and minimization) in which ratio of objective functions such as profit to cost, actual expense to standard expense, profit to time and cost to time, inventory to sale respectively. Fractional TP was first introduced by Swarup [3] in 1966 by the ratio of minimizing the cost and maximizing the service in the supply chain. The FTP is a challenging task that optimizes the ratio of one or more functions simultaneously and has received extensive attention from both theoretical and practical viewpoints. In real life situations, some parameters of FTP are imprecise due to various factors such as inadequate understanding of the problem domain, flaws in information, erroneous estimations and so on which affect the transportation cost. The launch of new products affects the demand for older products. The supply is affected when someone changes the demand suddenly by email or through an online system. Fuzzy numbers are applied to transport with these types of uncertain FTP such types of FTP is known as Fuzzy FTP. This imprecision can significantly affect the quality and reliability of optimization solutions. To deal with this uncertainty, Zadeh [4] was the first to introduce the fuzzy sets (FS) which provide the degree of membership function (MF). In reality, fuzzy sets effectively manage uncertainties caused by vagueness or partial membership of elements within a set, it cannot address all types of uncertainty found in various real-world problems, such as those involving incomplete data. In this case, Atanassov [5] introduced the intuitionistic fuzzy set (IFS) for handling both the degree of MF and non-MF (NMF). If the parameters of FTP are represented in intuitionistic fuzzy numbers, then the FTP is termed as a intuitionistic FTP. The IFS handles both the MF and NMF, but it is unable to handle indeterminacy. To resolve this, the concept of the neutrosophic set (NS) was introduced by Smarandache [6] which deals with both the degree of truth MF and falsity MF in addition to the indeterminacy degree. If the parameters of FTP are represented in neutrosophic numbers, then the FTP is termed as a neutrosophic FTP.

LITERATURE REVIEW

This section contains the literature review of fractional TP, fuzzy FTP, intuitionistic fuzzy FTP and neutrosophic FTP. Joshi and Gupta [7] proposed a new methodology for solving the fractional TP with varying supply and demand. Raina et al. [8] utilized the Karush-Kuhn-Tucker algorithm for solving the fractional TP. Bas et al. [9] extended the new iterative algorithm for solving the linear fractional TP. Arora and Jaggi [10] utilized fuzzy programming and goal programming approaches for solving the bilevel interval fractional TP. Munot and Ghadle [11] proposed the Ghadle-Munot algorithm for solving fractional TP. The aspirational level approach has emerged as one of the most effective approaches to solve multi-objective optimization problems in recent decades in multiple criteria decision-making problems. The concept of an aspiration level defines the minimum acceptable standard for each objective. This aspiration level guarantees that the solution meets the required criteria for each objective. If the solution fails to meet the aspiration level for any objective, the lower bound of the problem is adjusted, and the optimization process is repeated until the preferable solutions are found. Each objective is assigned an aspiration level, which can help prioritize them based on the decision makers (DMs) preferences. The proposed approach supports the DMs by adjusting the lower bound in problem related to weather conditions, land availability, optimal wind speed, environmental impact and high efficiency. It also enables the modification of production, maintenance and operational costs for windmill turbines. By optimizing these factors, the solution helps the DMs to make the right choices in financial and corporate planning. Mohamed [12] introduced the aspiration level membership objectives that incorporated fuzziness into the decision-making framework. Seikh et al. [13] proposed the aspirational level approach for solving the matrix games including the intuitionistic fuzzy goals and pay-offs. Sharma et al. [14] proposed the fuzzy aspirational approach for solving the fuzzy multi-objective fractional TP.

In real-world TP, parameters are unpredictable due to various factors, such as incomplete data, market fluctuations, environmental influences and so on. Köçken and Tiryaki [15] proposed compensatory fuzzy aggregation operators to solve the multi-objective linear TP. Liu [16] studied the bounds of TP for solving fuzzy fractional TP. Safi and Gasemi [17] studied the chance constrained method for solving the linear fractional TP under uncertain environment. Anukokila and Radhakrishnan [18] applied the goal programming approach for solving the fractional TP under fuzzy environment. Bhatia et al. [19] proposed the Mehar approach to obtain the fuzzy optimal solution for solving the linear fractional TP under fuzzy environment. Akram et al. [20] proposed a new approach to solve the fractional TP under interval valued fermatean fuzzy environment. Sheikhi and Ebadi [21] utilized the simplex method for solving the fractional TP under fuzzy environment. Akhtar and Islam [22] utilized bipolar fuzzy programming approach to solve the linear fractional TP under bipolar fuzzy environment. Bharati [23] developed a new methodology to solve the fractional TP under trapezoidal intuitionistic environment. The operators and properties of single-valued neutrosophic sets (SVNS) were analysed by Wang et al. [24]. Deli and Subas [25] addressed the special forms of single valued trapezoidal neutrosophic numbers (SVTrNNs) and solved the multi-criteria decision-making using weighted aggregation operator. Khalifa et al. [26] proposed a new method to solve the neutrosophic quadratic fractional TP. Khalifa et al. [27] applied the least cost method using Kuhn Tucker's condition to solve the fractional TP under neutrosophic environment.

Sensitivity analysis (SA) is the process of analysing the changes in the objective functions and right hand side constraints on the optimal value of the objective functions and their validity ranges. The purpose of SA is to identify the sensitivity ranges without affecting the current optimal compromise solution, which minimizes the possibility of errors. Midya and Roy [28] performed the SA of the parameters in the multi-objective fixed charge TP. Ghosh et al. [29] examined the SA of the supply, demand and conveyance parameters for type-2 multi-objective fixed charge solid TP (FCSTP). Ghosh et al. [30] carried out the SA for multi-objective FCSTP under intuitionistic environment. Midya and Roy [31] investigated the SA of the right hand side constraints for multi-stage multi-objective FCSTP under intuitionistic environment. From the above literature review, the comprehensive list related to fractional TP using transformation approaches in order to reduce the computational complexity is shown in Table 1.

From the above Table 1, it is clear that the majority of the work is focused on transforming two level to single level, multi-objectives to single objective. To the best of our knowledge, transformation of objective functions into the constraints approaches have received less attention. These are already known in the literature. Taking all these gaps into consideration, this study aims to fill this gap by the neutrosophic aspirational approach (NAA) which is proposed to transform the objective functions into the constraints and to obtain the optimal compromise solution and preferable solutions.

The motivation and contribution of this study are given as follows:

- In some situations, transforming objective functions into constraints helps the DMs by reducing computational complexity in decision-making problems and decreasing the cognitive load required to interpret trade-offs. This leads to faster convergence and improve overall outcomes. This motivates us to propose the transformation approach namely, neutrosophic aspirational approach (NAA) in this article which is a novelty of this study to transform the objective functions into the constraints for solving the fractional TP under neutrosophic environment. Each approach has its own strengths and weaknesses, and the specific approach is

Table 1. Literature survey for fractional TP using transformation approaches

References	Parameters nature				Approaches	Usage of Transformation approaches
	Cr	F	IF	NF		
Joshi and Gupta [7]	✓				New methodology	To transform two level mathematical model of FTP into one level of FTP
Raina et al. [8]	✓				Karush-Kuhn-Tucker algorithm	-
Bas et al. [9]	✓				Iterative algorithm	-
Arora and Jaggi [10]	✓				Fuzzy programming and goal programming approaches	To transform multi-objective FTP into single objective FTP
Sharma et al. [14]		✓			Fuzzy aspirational approach	To transform objective functions of fuzzy FTP into constraints of fuzzy FTP
Liu [16]		✓			Bounds of TP	To transform two level mathematical model of fuzzy FTP into one level of fuzzy FTP
Safi and Gasemi [17]		✓			Chance constrained method	-
Anukokila and Radhakrishnan [18]		✓			Goal programming approach	To transform multi-objective fuzzy FTP into single objective fuzzy FTP
Bhatia et al. [19]		✓			Mehar approach	-
Akram et al. [20]		✓			New approach	-
Sheikhi and Ebadi [21]		✓			Simplex method	-
Akhtar and Islam [22]		✓			Fuzzy programming approach	To transform multi-objective fuzzy FTP into single objective fuzzy FTP
Bharati [23]			✓		New methodology	-
Present paper				✓	Proposed Neutrosophic aspirational approach	To transform objective functions of FTP into constraints of FTP

Cr: Crisp; F: Fuzzy; IF: Intuitionistic fuzzy; NF: Neutrosophic fuzzy.

chosen according to the nature of the problem and the preferences of the DMs. The proposed approach is suitable for all the multi-objective optimization problems to achieve the goals in the decision making situations.

- In this paper, we have considered the neutrosophic fractional TP, where the objective function represents the ratio of SVTrN transportation cost to the profit. As uncertain data cannot be solved explicitly, sometimes it provides the negative value for the decision variable which violates the non-negativity constraints of the decision-making problem. In this paper, first we have applied the de-neutrosophication technique namely, weighted possibility mean (WPM) [31] to convert the neutrosophic FTP into its equivalent deterministic FTP. Next, we have utilized the proposed transformation approach namely, neutrosophic aspirational approach to transform the objective functions into the constraints. Then using the LINGO software, the reduced problem is solved to obtain the optimal compromise solution. Finally, to determine the sensitivity ranges of the constraints for the deterministic problem, the sensitivity analysis is performed. To illustrate the practicability, efficacy and utility of the solution approach using the proposed neutrosophic aspirational approach, two numerical examples are provided and the comparison was made with the existing approaches available in the literature. The obtained solution provides valuable insights for minimizing the transportation cost and maximizing the profit simultaneously to the DMs. This approach assists the DMs to attain all the objective functions up to the aspiration level, which symbolises the actual achievement of the maximum possible value to its corresponding membership value.

The paper is classified as: Section 2 deals with preliminaries and mathematical formulation of neutrosophic fractional TP. The solution approach using the proposed neutrosophic aspirational approach was illustrated in Section 3 to obtain the optimal compromise solution. Section 4 presents the numerical illustrations, while Section 5 deals with the comparative analysis. Section 6 includes the conclusions along with future scopes.

PRELIMINARIES AND MATHEMATICAL FORMULATION

In this section, some basic definitions related to the NS [6], SVN sets [24], SVTrNNs and their arithmetic operations [25] are presented.

Definition 2.1: Weighted Possibility Mean of single valued trapezoidal neutrosophic numbers [32]

Let $\tilde{r}=\left(s_{\tilde{r}}^1, s_{\tilde{r}}^2, s_{\tilde{r}}^3, s_{\tilde{r}}^4; k_{\tilde{r}}, l_{\tilde{r}}, m_{\tilde{r}}\right)$ be single-valued trapezoidal neutrosophic number and the possibilistic mean of truth, indeterminacy and falsity MF denoted by $g(\tilde{r}(\alpha))$, $g(\tilde{r}(\beta))$ and $g(\tilde{r}(\gamma))$ respectively. The weighted possibility mean is defined as $B(\tilde{r},\mu)$ in which the DM's always aim to maximize the degree of truth membership, minimize the degree of indeterminacy and falsity membership, as follows:

$$B(\tilde{r},\mu)=\mu g(\tilde{r}(\alpha))+(1-\mu)g(\tilde{r}(\beta))+(1-\mu)g(\tilde{r}(\gamma))$$

where $g(\tilde{r}(\alpha))=\left[\frac{s_{\tilde{r}}^1+2s_{\tilde{r}}^2+2s_{\tilde{r}}^3+s_{\tilde{r}}^4}{6}\right]k_{\tilde{r}}^2$,

$$g(\tilde{r}(\beta))=\left[\frac{\left(2s_{\tilde{r}}^1+s_{\tilde{r}}^2+s_{\tilde{r}}^3+2s_{\tilde{r}}^4\right)-\left(s_{\tilde{r}}^1-s_{\tilde{r}}^2-s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)l_{\tilde{r}}-\left(s_{\tilde{r}}^1+2s_{\tilde{r}}^2+2s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)l_{\tilde{r}}^2}{6}\right] \text{ and}$$

$$g(\tilde{r}(\gamma))=\left[\frac{\left(2s_{\tilde{r}}^1+s_{\tilde{r}}^2+s_{\tilde{r}}^3+2s_{\tilde{r}}^4\right)-\left(s_{\tilde{r}}^1-s_{\tilde{r}}^2-s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)m_{\tilde{r}}-\left(s_{\tilde{r}}^1+2s_{\tilde{r}}^2+2s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)m_{\tilde{r}}^2}{6}\right]$$

Using Definition 2.1, the weighted possibility mean of single valued trapezoidal neutrosophic number in fractional form is as follows.

Let $\frac{\tilde{r}}{\tilde{t}}=\frac{\left(s_{\tilde{r}}^1, s_{\tilde{r}}^2, s_{\tilde{r}}^3, s_{\tilde{r}}^4; k_{\tilde{r}}, l_{\tilde{r}}, m_{\tilde{r}}\right)}{\left(s_{\tilde{t}}^1, s_{\tilde{t}}^2, s_{\tilde{t}}^3, s_{\tilde{t}}^4; k_{\tilde{t}}, l_{\tilde{t}}, m_{\tilde{t}}\right)}$ be single-valued trapezoidal neutrosophic number and the possibilistic mean of truth, indeterminacy and falsity MF denoted by $\frac{g(\tilde{r}(\alpha))}{g(\tilde{t}(\alpha))}$, $\frac{g(\tilde{r}(\beta))}{g(\tilde{t}(\beta))}$ and $\frac{g(\tilde{r}(\gamma))}{g(\tilde{t}(\gamma))}$ respectively. The weighted possibility mean is defined as $\frac{B(\tilde{r},\mu)}{B(\tilde{t},\mu)}$ in which the DM's always aim to maximize the degree of truth membership, minimize the degree of indeterminacy and falsity membership, as follows:

$$\frac{B(\tilde{r},\mu)}{B(\tilde{t},\mu)}=\frac{\mu g(\tilde{r}(\alpha))+(1-\mu)g(\tilde{r}(\beta))+(1-\mu)g(\tilde{r}(\gamma))}{\mu g(\tilde{t}(\alpha))+(1-\mu)g(\tilde{t}(\beta))+(1-\mu)g(\tilde{t}(\gamma))}$$

where
$$\frac{g(\tilde{r}(\alpha))}{g(\tilde{t}(\alpha))}=\frac{\left[\frac{s_{\tilde{r}}^1+2s_{\tilde{r}}^2+2s_{\tilde{r}}^3+s_{\tilde{r}}^4}{6}\right]k_{\tilde{r}}^2}{\left[\frac{s_{\tilde{t}}^1+2s_{\tilde{t}}^2+2s_{\tilde{t}}^3+s_{\tilde{t}}^4}{6}\right]k_{\tilde{t}}^2},$$

$$\frac{g(\tilde{r}(\beta))}{g(\tilde{t}(\beta))}=\frac{\left[\frac{\left(2s_{\tilde{r}}^1+s_{\tilde{r}}^2+s_{\tilde{r}}^3+2s_{\tilde{r}}^4\right)-\left(s_{\tilde{r}}^1-s_{\tilde{r}}^2-s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)l_{\tilde{r}}-\left(s_{\tilde{r}}^1+2s_{\tilde{r}}^2+2s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)l_{\tilde{r}}^2}{6}\right]}{\left[\frac{\left(2s_{\tilde{t}}^1+s_{\tilde{t}}^2+s_{\tilde{t}}^3+2s_{\tilde{t}}^4\right)-\left(s_{\tilde{t}}^1-s_{\tilde{t}}^2-s_{\tilde{t}}^3+s_{\tilde{t}}^4\right)l_{\tilde{t}}-\left(s_{\tilde{t}}^1+2s_{\tilde{t}}^2+2s_{\tilde{t}}^3+s_{\tilde{t}}^4\right)l_{\tilde{t}}^2}{6}\right]} \text{ and}$$

$$\frac{g(\tilde{r}(\gamma))}{g(\tilde{t}(\gamma))}=\frac{\left[\frac{\left(2s_{\tilde{r}}^1+s_{\tilde{r}}^2+s_{\tilde{r}}^3+2s_{\tilde{r}}^4\right)-\left(s_{\tilde{r}}^1-s_{\tilde{r}}^2-s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)m_{\tilde{r}}-\left(s_{\tilde{r}}^1+2s_{\tilde{r}}^2+2s_{\tilde{r}}^3+s_{\tilde{r}}^4\right)m_{\tilde{r}}^2}{6}\right]}{\left[\frac{\left(2s_{\tilde{t}}^1+s_{\tilde{t}}^2+s_{\tilde{t}}^3+2s_{\tilde{t}}^4\right)-\left(s_{\tilde{t}}^1-s_{\tilde{t}}^2-s_{\tilde{t}}^3+s_{\tilde{t}}^4\right)m_{\tilde{t}}-\left(s_{\tilde{t}}^1+2s_{\tilde{t}}^2+2s_{\tilde{t}}^3+s_{\tilde{t}}^4\right)m_{\tilde{t}}^2}{6}\right]}$$

Problem Description

In transportation systems, the shipment of products from different sources to various destinations is a significant challenge. To address this, we consider a fractional transportation problem where the objective function is formulated as a ratio of transportation cost incurred and the profit generated for shipping goods from each source to each destination. A major challenge in real-world transportation problems is the presence of uncertainty, imprecision and indeterminacy in various parameters such as supply, demand, cost and profit. To effectively manage these uncertainties, we incorporate a neutrosophic environment, where all parameters are represented using single-valued trapezoidal neutrosophic numbers. The problem is formulated with *m* sources supplying goods to *n* destinations, where each source has a certain capacity, and each destination has a specific demand. The decision variables determine the quantity of goods transported from each source to each destination while ensuring that the total cost-to-profit ratio is minimized or optimized based on the specific problem constraints. The primary goal is to determine the optimal compromise solution for efficiently transporting the products from *m* sources to *n* destinations.

Notations

$\tilde{a}_i^N = (a_i^1, a_i^2, a_i^3, a_i^4; a_i'^1, a_i'^2, a_i'^3)$: single valued trapezoidal neutrosophic supply at i^{th} origin

$\tilde{b}_j^N = (b_j^1, b_j^2, b_j^3, b_j^4; b_j'^1, b_j'^2, b_j'^3)$: single valued trapezoidal neutrosophic demand at j^{th} destination.

$\tilde{c}_{ij}^N = (c_{ij}^1, c_{ij}^2, c_{ij}^3, c_{ij}^4; c_{ij}'^1, c_{ij}'^2, c_{ij}'^3)$: objective function of single valued trapezoidal neutrosophic transportation cost from i^{th} source to j^{th} destination.

$\tilde{p}_{ij}^N = (p_{ij}^1, p_{ij}^2, p_{ij}^3, p_{ij}^4; p_{ij}'^1, p_{ij}'^2, p_{ij}'^3)$: objective function of single valued trapezoidal neutrosophic transportation profit from i^{th} source to j^{th} destination.

x_{ij}: quantity of products transported from i^{th} source to j^{th} destination.

Formulation

Let there be 'm' sources and 'n' destinations that are employed to transport the electronic gadgets from various sources to different destinations. This research article considers the neutrosophic fractional TP where the ratio of the transportation cost to the transportation profit as the objective function. The DMs goal is to reduce the transportation cost and increase the profit of electronic gadgets transported from various sources to different destinations. The mathematical formulation of neutrosophic fractional TP [27] is given as follows.

$$(G_1)\ Minimize\ \ \tilde{Z}^N(x) = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} \tilde{c}_{ij}^N x_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n} \tilde{p}_{ij}^N x_{ij}}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \le \tilde{a}_i^N, i = 1,2,\ldots,m \tag{1}$$

$$\sum_{i=1}^{m} x_{ij} \ge \tilde{b}_j^N, j = 1,2,\ldots,n \tag{2}$$

$$x_{ij} \ge 0^N \ \ for\ all\, i, j \tag{3}$$

In the problem (G_1), the objective function represents the ratio of transportation cost that would be minimized and the profit that would be maximized. The constraints (1), (2) and (3) display as source, demand and nonnegativity restriction respectively.

Deterministic Formulation of Problem (G1)

There are various de-neutrosophication techniques available in the literature. In this paper, an accurate representation is achieved by the weighted possibility mean [32], which enables the quantification of the certainty associated with each parameter. The weighted possibility mean is utilized to transform the neutrosophic FTP (G_1) into its deterministic FTP (G_2). The reduced problem (G_2) is written based on [33-35] as follows.

$$(G_2)\ Minimize\ \Re\left(\tilde{Z}^N(x)\right) = \frac{\Re\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left(c_{ij}^1, c_{ij}^2, c_{ij}^3, c_{ij}^4, c_{ij}'^1, c_{ij}'^2, c_{ij}'^3\right) x_{ij}\right)}{\Re\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left(p_{ij}^1, p_{ij}^2, p_{ij}^3, p_{ij}^4, p_{ij}'^1, p_{ij}'^2, p_{ij}'^3\right) x_{ij}\right)}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \le \Re\ \left(a_i^1, a_i^2, a_i^3, a_i^4; a_i'^1, a_i'^2, a_i'^3\right),\ i = 1,2,\ldots,m$$

$$\sum_{i=1}^{m} x_{ij} \ge \Re\ \left(b_j^1, b_j^2, b_j^3, b_j^4; b_j'^1, b_j'^2, b_j'^3\right),\ j = 1,2,\ldots,n$$

$$x_{ij} \ge 0^N \ \ for\ all\, i, j$$

where $\Re\left(\tilde{Z}^N(x)\right) = Z(x)$

As in [14], split the problem (G_2) into two sub-problems in which the numerator is considered as minimizing objective function (G_3) and the denominator is considered as maximizing objective function (G_4).

$$(G_3)\, Minimize\ \Re\left(\tilde{Z}_{nr}^N(x)\right) = \Re\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left(c_{ij}^1, c_{ij}^2, c_{ij}^3, c_{ij}^4, c_{ij}'^1, c_{ij}'^2, c_{ij}'^3\right) x_{ij}\right)$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \le \Re\left(a_i^1, a_i^2, a_i^3, a_i^4; a_i'^1, a_i'^2, a_i'^3\right), i = 1,2,\ldots,m$$

$$\sum_{i=1}^{m} x_{ij} \ge \Re\left(b_j^1, b_j^2, b_j^3, b_j^4; b_j'^1, b_j'^2, b_j'^3\right), j = 1,2,\ldots,n$$

$$x_{ij} \ge 0^N \ \ for\ all\, i, j$$

$$(G_4)\, Maximize\ \Re\left(\tilde{Z}_{dr}^N(x)\right) = \Re\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left(p_{ij}^1, p_{ij}^2, p_{ij}^3, p_{ij}^4, p_{ij}'^1, p_{ij}'^2, p_{ij}'^3\right) x_{ij}\right)$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \le \Re\left(a_i^1, a_i^2, a_i^3, a_i^4; a_i'^1, a_i'^2, a_i'^3\right),\ i = 1,2,\ldots,m$$

$$\sum_{i=1}^{m} x_{ij} \ge \Re\left(b_j^1, b_j^2, b_j^3, b_j^4; b_j'^1, b_j'^2, b_j'^3\right),\ j = 1,2,\ldots,n$$

$$x_{ij} \ge 0^N \ \ for\ all\, i, j$$

$\tilde{b}_1^N \; \tilde{b}_2^N \; \tilde{b}_3^N$

where $\Re\left(\tilde{Z}_{nr}^N(x)\right)=Z_{nr}(x)$ and $\Re\left(\tilde{Z}_{dr}^N(x)\right)=Z_{dr}(x)$

In real life, there are almost no problems where objective functions and constraints are fixed from the beginning, sometimes we need to transform them according to the circumstances. In that situation, it is necessary to transform the objective functions into constraints. To handle this, we have proposed the neutrosophic aspirational approach based on membership goal for aspiration level [12] which is used to transform the objective functions into constraints. The solution approach using the proposed neutrosophic aspirational approach has been discussed in the next section.

Solution Approach

In this section, we present the solution approach using the proposed neutrosophic aspirational approach which transforms the objective functions into the constraints. This approach is based on membership goal for aspiration level [12] by maximizing the degree of truth and indeterminacy and by minimizing the degree of falsity. The procedure of the solution approach using the proposed neutrosophic aspirational approach which proceeds as follows:

Step 1 Formulate the neutrosophic fractional TP (NFTP) (G_1).

Step 2 Transform the neutrosophic fractional TP (G_1) into its equivalent deterministic fractional TP (G_2) using the weighted possibility mean (WPM) [32]. In WPM, μ be any value between 0 and 1. Here we have chosen $\mu = 1$.

Step 3 Split the problem (G_2) into two subproblems (G_3) and (G_4) in which the numerator is considered as minimizing objective function and the denominator as maximizing objective function.

Step 4 Solve the subproblems (G_3) and (G_4) of deterministic fractional TP to obtain the optimal solution using the zero point method [34]. Then using the obtained optimal solution, the pay-off matrix is created in Table 2.

Step 5 Transform the objective functions of (G_3) and (G_4) into the constraints using the proposed transformation approach namely, neutrosophic aspirational approach based on membership goal for aspiration level [12]. The proposed approach enhances transportation systems by addressing uncertainty, improving adaptability, and setting realistic goals to ensure efficiency and flexibility. It enables intelligent, data-driven, and flexible decision-making to develop sustainable, efficient and future-oriented transportation systems. The technique of the proposed approach is as follows:

Table 2. Pay-off matrix

	Z_{nr}	Z_{dr}
X_{nr}	$Z_{nr}(X_{nr})$	$Z_{dr}(X_{nr})$
X_{dr}	$Z_{nr}(X_{dr})$	$Z_{dr}(X_{dr})$

Step 5a Consider the truth, indeterminacy and falsity membership function (MF) (24-26) for the minimization objective function (G_3) available in [33]. Based on the problem G_3 [33], the truth MF $T_a(z_{dr}(x))$, indeterminacy MF $I_\beta(z_{dr}(x))$ and falsity MF $F_\gamma(z_{dr}(x))$ for the maximization objective function (G_4) are as follows.

$$T_a\left(z_{dr}(x)\right)=\begin{cases}1, & z_{dr}(x)>U_{dr}^T\\ \dfrac{z_{dr}(x)-L_{dr}^T}{U_{dr}^T-L_{dr}^T}, & L_{dr}^T\le z_{dr}(x)\le U_{dr}^T\\ 0, & z_{dr}(x)<L_{dr}^T\end{cases} \tag{4}$$

$$I_\beta\left(z_{dr}(x)\right)=\begin{cases}1, & z_{dr}(x)>U_D^I\\ \dfrac{z_{dr}(x)-L_{dr}^I}{U_{dr}^I-L_{dr}^I}, & L_{dr}^I\le z_{dr}(x)\le U_{dr}^I\\ 0, & z_{dr}(x)<L_D^I\end{cases} \tag{5}$$

$$F_\gamma\left(z_{dr}(x)\right)=\begin{cases}1, & z_{dr}(x)<L_{dr}^F\\ \dfrac{U_{dr}^F-z_{dr}(x)}{U_{dr}^F-L_{dr}^F}, & L_{dr}^F\le z_{dr}(x)\le U_{dr}^F\\ 0, & z_{dr}(x)>U_{dr}^F\end{cases} \tag{6}$$

where U_{dr}^T and L_{dr}^T are UB and LB for truth MF of G_4, U_{dr}^I and L_{dr}^I are UB and LB for indeterminacy MF of G_4 and U_{dr}^F and L_{dr}^F are UB and LB for falsity MF of G_4.

Step 5b Consider the UB and LB for truth, indeterminacy and falsity MF (21-23) for the problem (G_3) and (G_4) are available in [33]. The truth and indeterminacy MF for the problem (G_3) are available in the problem (P_7) [33]. Based on the problem (P_7) [33], the falsity MF for the problem (G_3), truth, indeterminacy and falsity MF for the problem (G_4) are shown in Table 3.

Step 6 Solve the reduced problem using LINGO software to obtain the optimal compromise solution (OCS). Finally, to compute the neutrosophic OCS substitute the optimal allocations of (G_3) and (G_4) in the problem (G_1). The proposed aspirational approach assures that the solution attained is satisfactory for all objective functions. If the solution is not satisfied with the DMs expectation for each objective, the lower bound is adjusted. Then go to Step 7.

Step 7 Change the lower bound for G_4 to the new value which lies between $Z_{dr}(X_{nr}) \le Z_{dr}(X) \le Z_{dr}(X_{dr})$. Then go to Step 5 and the process is iterated until the best suitable OCS for the problem is attained.

Step 8 Determine the sensitivity range for the supply and demand constraints in the optimal allotment using [30]. The calculated range helps the DMs to identify that how much variations in the input values for a given variable impact the results for the problem. Figure 1 represents the flowchart for the solution approach.

The proposed approach for solving the fractional TP under neutrosophic environment is illustrated using the

Table 3. UB and LB for truth, indeterminacy and falsity MF for (G_3) and (G_4)

For the problem G3		For the problem G4	
Max $\alpha - \beta + \gamma$ Subject to : Truth MF $z_{nr}(x) \le U^T_{nr} - \alpha\left(U^T_{nr} - L^T_{nr}\right)$ [33]	(4)	*Max* $\alpha - \beta + \gamma$ Subject to: Truth MF $\alpha \le T_\alpha\left(z_{dr}(x)\right)$ where $T_\alpha\left(z_{dr}(x)\right) = \frac{z_{dr}(x) - L^T_{dr}}{U^T_{dr} - L^T_{dr}}$ $\alpha \le \frac{z_{dr}(x) - L^T_{dr}}{U^T_{dr} - L^T_{dr}}$ $z_{dr}(x) \ge \alpha\left(U^T_{dr} - L^T_{dr}\right) + L^T_{dr}$	(7)
Indeterminacy MF $z_{nr}(x) \le U^I_{nr} - \beta\left(U^I_{nr} - L^I_{nr}\right)$ [33]	(5)	Indeterminacy MF $\beta \le I_\beta\left(z_{dr}(x)\right)$ where $I_\beta\left(z_{dr}(x)\right) = \frac{z_{dr}(x) - L^I_{dr}}{U^I_{dr} - L^I_{dr}}$ $\beta \le \frac{z_2(x) - L^I_{dr}}{U^I_{dr} - L^I_{dr}}$ $z_{dr}(x) \ge \beta\left(U^I_{dr} - L^I_{dr}\right) + L^I_{dr}$	(8)
Falsity MF $\gamma \le F_\gamma\left(z_{nr}(x)\right)$ where $F_\gamma\left(z_{nr}(x)\right) = \frac{z_{nr}(x) - L^F_{nr}}{U^F_{nr} - L^F_{nr}}$ $\gamma \le \frac{z_{nr}(x) - L^F_{nr}}{U^F_{nr} - L^F_{nr}}$ $z_{nr}(x) \ge \gamma\left(U^F_{nr} - L^F_{nr}\right) + L^F_{nr}$ along with the constraints (1) - (3) $\alpha \ge \gamma, \alpha \ge \beta, \alpha + \beta + \gamma \le 3, \alpha, \beta, \gamma \in [0,1]$	(6)	Falsity MF $\gamma \le F_\gamma\left(z_{dr}(x)\right)$ where $F_\gamma\left(z_{dr}(x)\right) = \frac{U^F_{dr} - z_{dr}(x)}{U^F_{dr} - L^F_{dr}}$ $\gamma \le \frac{U^F_{dr} - z_{dr}(x)}{U^F_{dr} - L^F_{dr}}$ $z_{dr}(x) \le U^F_{dr} - \gamma\left(U^F_{dr} - L^F_{dr}\right)$ along with the constraints (1) - (3) $\alpha \ge ,\gamma \;\; \alpha \ge \beta \;\; \alpha + \beta + \gamma \le 3, \alpha, \beta, \gamma \in [0,1]$	(9)

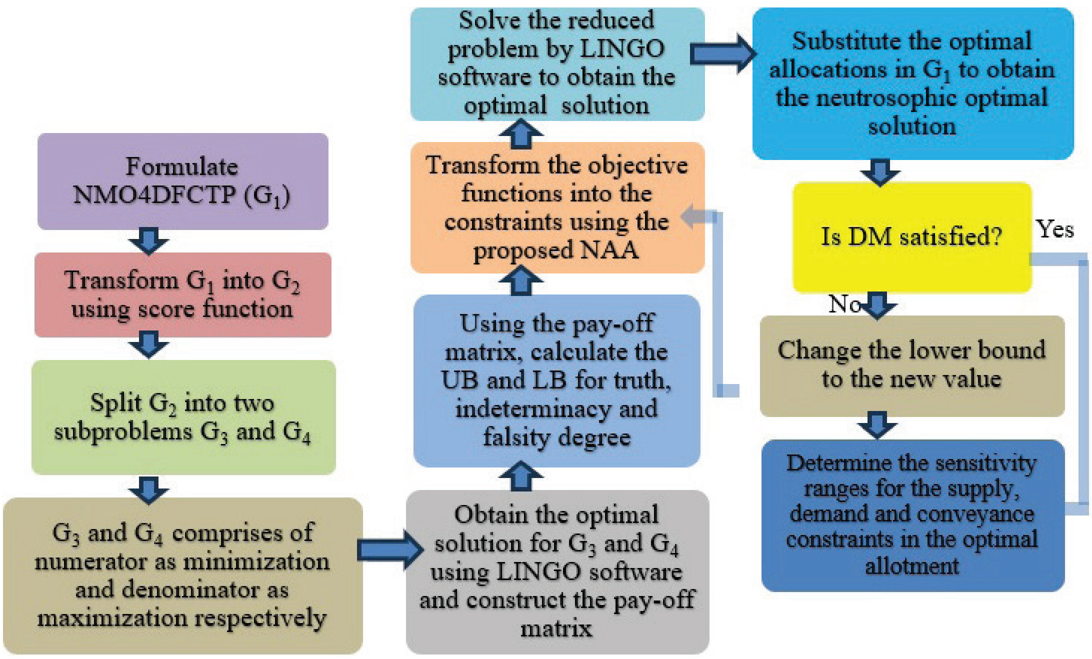

Figure 1. Flowchart for the solution approach.

two numerical examples that are given in the following section. The data of Example 1 is taken from [27] and Example 2 is taken due to our preference.

Numerical Example 1

Every year, online shopping sites transport the electronic gadgets throughout the world. In these, Amazon is one of the main sites for online shopping. There are three retailers from whom the electronic gadgets can be transported from Tamil Nadu, New Delhi and West Bengal to the four customers namely, Hyderabad, Gujarat, Assam and Mumbai. In order to increase the profit, electronic gadgets must be transported to every retailer in bulk. Due to various unforeseen factors like conditions of road, weather, traffic, price variations and so on, the parameters are considered as neutrosophic numbers. The yearly capacities of the electronic gadgets are $\tilde{a}_1^N$, $\tilde{a}_2^N$ and $\tilde{a}_3^N$units and the yearly requirements of the electronic gadgets are $\tilde{b}_1^N$, $\tilde{b}_2^N$, $\tilde{b}_3^N$ and $\tilde{b}_4^N$ units respectively. Let us assume that the ratio of minimization of transportation cost $\left(\tilde{c}_{ij}^N\right)$ to the maximization of the profit $\left(\tilde{p}_{ij}^N\right)$ as the objective function to transport the electronic gadgets. The goal of the fractional TP is to reduce the transportation cost and increase the profit simultaneously. The problem (G_1) is modelled as fully SVTrN fractional TP where all the coefficients of transportation cost, profit, supply and demand constraints are shown in Table 4.

Supplies: $\tilde{a}_1^N$ = (190, 250, 260, 300; 0.7, 0.2, 0.1), $\tilde{a}_2^N$ = (340, 380, 447, 500; 0.7, 0.2, 0.1) and $\tilde{a}_3^N$ = (283, 300, 350, 400; 0.7, 0.2, 0.1)

Demands: $\tilde{b}_1^N$ = (157, 163, 169, 178; 0.7, 0.1, 0.2), $\tilde{b}_2^N$ = (340, 380, 446, 500; 0.7, 0.1, 0.2), $\tilde{b}_3^N$ = (157, 163, 169, 178; 0.7, 0.1, 0.2) and $\tilde{b}_4^N$ = (190, 250, 260, 300; 0.7, 0.2, 0.1)

Transportation cost :

$\tilde{c}_{11}^N$ = (14, 17, 21, 28; 0.7, 0.1, 0.2); $\tilde{c}_{12}^N$ = (28, 30, 35, 44; 0.9, 0.2, 0.6); $\tilde{c}_{13}^N$ = (10, 16, 18, 20; 0.8, 0.1, 0.1); $\tilde{c}_{14}^N$ = (17, 25, 30, 35; 0.7, 0.2, 0.4); $\tilde{c}_{21}^N$ = (18, 20, 22, 25; 0.8, 0.2, 0.7); $\tilde{c}_{22}^N$ = (14, 17, 21, 28; 0.9, 0.1, 0.1); $\tilde{c}_{23}^N$ = (31, 35, 40, 45; 0.6, 0.4, 0.5); $\tilde{c}_{24}^N$ = (l6, l8, 20, 26; 0.8, 0.2, 0.7); $\tilde{c}_{31}^N$ = (18, 21, 23, 26; 0.8, 0.2, 0.6); $\tilde{c}_{32}^N$ = (14, 18, 20, 24; 0.6, 0.4, 0.5); $\tilde{c}_{33}^N$ = (25, 30, 35, 40; 0.6, 0.2, 0.3); $\tilde{c}_{34}^N$ = (18, 21, 23, 26; 0.8, 0.2, 0.6)

Table 4. Neutrosophic transportation cost $\left(\tilde{c}_{ij}^N\right)$ to profit $\left(\tilde{p}_{ij}^N\right)$

S_i \ D_j	D_1	D_2	D_3	D_4	Supply
S_1	$\frac{\tilde{c}_{11}^N}{\tilde{p}_{11}^N}$	$\frac{\tilde{c}_{12}^N}{\tilde{p}_{12}^N}$	$\frac{\tilde{c}_{13}^N}{\tilde{p}_{13}^N}$	$\frac{\tilde{c}_{14}^N}{\tilde{p}_{14}^N}$	$\tilde{a}_1^N$
S_2	$\frac{\tilde{c}_{21}^N}{\tilde{p}_{21}^N}$	$\frac{\tilde{c}_{22}^N}{\tilde{p}_{22}^N}$	$\frac{\tilde{c}_{23}^N}{\tilde{p}_{23}^N}$	$\frac{\tilde{c}_{24}^N}{\tilde{p}_{24}^N}$	$\tilde{a}_2^N$
S_3	$\frac{\tilde{c}_{31}^N}{\tilde{p}_{31}^N}$	$\frac{\tilde{c}_{32}^N}{\tilde{p}_{32}^N}$	$\frac{\tilde{c}_{33}^N}{\tilde{p}_{33}^N}$	$\frac{\tilde{c}_{34}^N}{\tilde{p}_{34}^N}$	$\tilde{a}_3^N$
Demand	$\tilde{b}_1^N$	$\tilde{b}_2^N$	$\tilde{b}_3^N$	$\tilde{b}_4^N$	

Neutrosophic Profit:

$\tilde{p}_{11}^N$ = (25, 30, 35, 40; 0.6, 0.2, 0.3); $\tilde{p}_{12}^N$ = (17, 25, 30, 35; 0.7, 0.2, 0.4); $\tilde{p}_{13}^N$ = (28, 30, 35, 44; 0.9, 0.2, 0.6); $\tilde{p}_{14}^N$ = (18, 20, 22, 25; 0.8, 0.2, 0.7); $\tilde{p}_{21}^N$ = (18, 20, 22, 25; 0.8, 0.2, 0.4); $\tilde{p}_{22}^N$ = (14, 18, 20, 24; 0.6, 0.4, 0.5); $\tilde{p}_{23}^N$ = (23, 27, 30, 35; 0.7, 0.2, 0.4); $\tilde{p}_{24}^N$ = (l7, 25, 30, 35; 0.7, 0.2, 0.4); $\tilde{p}_{31}^N$ = (23, 28, 30, 34; 0.7, 0.2, 0.4); $\tilde{p}_{32}^N$ = (25, 30, 35, 40; 0.6, 0.2, 0.3); $\tilde{p}_{33}^N$ = (14, 17, 21, 28; 0.9, 0.1, 0.1); $\tilde{p}_{34}^N$ = (14, 17, 21, 28; 0.7, 0.1, 0.2)

Now compute the weighted possibility mean using the possibilistic mean values of truth, indeterminacy and falsity MF. Using Definition 2.1, the representation of weighted possibility mean for the first cell $\frac{\tilde{c}_{11}^N}{\tilde{p}_{11}^N}$ from Table 4 is as follows:

$$\frac{\tilde{c}_{11}^N}{\tilde{p}_{11}^N} = \frac{\mu\left[g\left(\tilde{c}_{11}^N(\alpha)\right)\right] + (1-\mu)\left[g\left(\tilde{c}_{11}^N(\beta)\right) + g\left(\tilde{c}_{11}^N(\gamma)\right)\right]}{\mu\left[g\left(\tilde{p}_{11}^N(\alpha)\right)\right] + (1-\mu)\left[g\left(\tilde{p}_{11}^N(\beta)\right) + g\left(\tilde{p}_{11}^N(\gamma)\right)\right]} \tag{10}$$

Using Definition 2.1, the possibilistic mean of truth MF is as follows:

$$\frac{g\left(\tilde{c}_{11}^N(\alpha)\right)}{g\left(\tilde{p}_{11}^N(\alpha)\right)} = \frac{\left[\frac{s_{\tilde{r}}^1 + 2s_{\tilde{r}}^2 + 2s_{\tilde{r}}^3 + s_{\tilde{r}}^4}{6}\right]k_{\tilde{r}}^2}{\left[\frac{s_{\tilde{t}}^1 + 2s_{\tilde{t}}^2 + 2s_{\tilde{t}}^3 + s_{\tilde{t}}^4}{6}\right]k_{\tilde{t}}^2} = \frac{\left[\frac{(14) + 2(17) + 2(21) + 28}{6}\right](0.7)^2}{\left[\frac{(25) + 2(30) + 2(35) + 40}{6}\right](0.6)^2} = \frac{9.63}{11.7} \simeq \frac{10}{12}$$

Using Definition 2.1, the possibilistic mean of indeterminacy MF is as follows:

$$\frac{g\left(\tilde{c}_{11}^N(\beta)\right)}{g\left(\tilde{p}_{11}^N(\beta)\right)} = \frac{\left[\frac{\left(2s_{\tilde{r}}^1 + s_{\tilde{r}}^2 + s_{\tilde{r}}^3 + 2s_{\tilde{r}}^4\right) - \left(s_{\tilde{r}}^1 - s_{\tilde{r}}^2 - s_{\tilde{r}}^3 + s_{\tilde{r}}^4\right)l_{\tilde{r}} - \left(s_{\tilde{r}}^1 + 2s_{\tilde{r}}^2 + 2s_{\tilde{r}}^3 + s_{\tilde{r}}^4\right)l_{\tilde{r}}^2}{6}\right]}{\left[\frac{\left(2s_{\tilde{t}}^1 + s_{\tilde{t}}^2 + s_{\tilde{t}}^3 + 2s_{\tilde{t}}^4\right) - \left(s_{\tilde{t}}^1 - s_{\tilde{t}}^2 - s_{\tilde{t}}^3 + s_{\tilde{t}}^4\right)l_{\tilde{t}} - \left(s_{\tilde{t}}^1 + 2s_{\tilde{t}}^2 + 2s_{\tilde{t}}^3 + s_{\tilde{t}}^4\right)l_{\tilde{t}}^2}{6}\right]}$$

$$= \frac{\left[\frac{(2(14) + 17 + 21 + 2(28)) - (14 - 17 - 21 + 28)(0.1) - (14 + 2(17) + 2(21) + 28)(0.1)^2}{6}\right]}{\left[\frac{(2(25) + 30 + 35 + 2(40)) - (25 - 30 - 35 + 40)(0.2) - (25 + 2(30) + 2(35) + 40)(0.2)^2}{6}\right]} = \frac{20.07}{31.2} \simeq \frac{20}{31}$$

Using Definition 2.1, the possibilistic mean of falsity MF is as follows:

$$\frac{g\left(\tilde{c}_{11}^N(\gamma)\right)}{g\left(\tilde{p}_{11}^N(\gamma)\right)} = \frac{\left[\frac{\left(2s_{\tilde{r}}^1 + s_{\tilde{r}}^2 + s_{\tilde{r}}^3 + 2s_{\tilde{r}}^4\right) - \left(s_{\tilde{r}}^1 - s_{\tilde{r}}^2 - s_{\tilde{r}}^3 + s_{\tilde{r}}^4\right)m_{\tilde{r}} - \left(s_{\tilde{r}}^1 + 2s_{\tilde{r}}^2 + 2s_{\tilde{r}}^3 + s_{\tilde{r}}^4\right)m_{\tilde{r}}^2}{6}\right]}{\left[\frac{\left(2s_{\tilde{t}}^1 + s_{\tilde{t}}^2 + s_{\tilde{t}}^3 + 2s_{\tilde{t}}^4\right) - \left(s_{\tilde{t}}^1 - s_{\tilde{t}}^2 - s_{\tilde{t}}^3 + s_{\tilde{t}}^4\right)m_{\tilde{t}} - \left(s_{\tilde{t}}^1 + 2s_{\tilde{t}}^2 + 2s_{\tilde{t}}^3 + s_{\tilde{t}}^4\right)m_{\tilde{t}}^2}{6}\right]}$$

$$= \frac{\left[\frac{(2(14) + 17 + 21 + 2(28)) - (14 - 17 - 21 + 28)(0.2) - (14 + 2(17) + 2(21) + 28)(0.2)^2}{6}\right]}{\left[\frac{(2(25) + 30 + 35 + 2(40)) - (25 - 30 - 35 + 40)(0.3) - (25 + 2(30) + 2(35) + 40)(0.3)^2}{6}\right]} = \frac{19.41}{29.57} \simeq \frac{19}{30}$$

By substituting the values of possibilistic mean of truth, indeterminacy and falsity MF in eqn.(10), we obtain

$$\frac{\tilde{c}_{11}^{N}}{\tilde{p}_{11}^{N}} = \frac{\mu\,(10) + (1-\mu\,)(20+19)}{\mu\,(12) + (1-\mu\,)(31+30)} \tag{11}$$

where μ be any value between 0 and 1. Here $\mu = 1$ is chosen to reduce the weighted possibility mean of neutrosophic fractional TP into its deterministic fractional TP, then we obtain $\frac{\tilde{c}_{11}^{N}}{\tilde{p}_{11}^{N}} = \frac{10}{12}$. In the same manner, we compute the values of possibilistic mean of truth, indeterminacy and falsity MF of the other cells in Table 4. The reduced deterministic fractional TP using WPM is shown in Table 5.

The above problem is unbalanced, so balance it. Next as in Step 3, split the problem into two subproblems in which the numerator is considered as minimizing objective function and the denominator is considered as maximizing objective function which are given below (Table 6).

By step 4, the above deterministic fractional TP is solved using zero point method [34] to obtain the optimal solution. The optimal solution of transportation cost of electronic gadgets $Z_{nr}(x)$ is 5177 at the allocations $x_{11} = 82$, $x_{13} = 4l$, $x_{22} = 40$, $x_{23} = 41$, $x_{24} = 123$, $x_{32} = 162$, $x_{42} = 2$ and the rest are all zero. Similarly, the optimal solution of transportation profit of electronic gadgets $Z_{dr}(x)$ is 7426 at the allocations $x_{12} = 40$, $x_{13} = 82$, $x_{14} = 1$, $x_{21} = 82$, $x_{24} = 122$, $x_{32} = 162$, $x_{42} = 2$ and the rest are all zero. Using the obtained optimal solutions of $Z_{nr}(x)$ and $Z_{dr}(x)$ the pay-off matrix is constructed in Table 7.

Table 5. Deterministic c_{ij} to p_{ij} using WPM

S_i \ D_j	D_1	D_2	D_3	D_4	Supply
S_1	$\frac{10}{12}$	$\frac{27}{13}$	$\frac{10}{27}$	$\frac{13}{14}$	123
S_2	$\frac{14}{14}$	$\frac{16}{7}$	$\frac{14}{14}$	$\frac{13}{13}$	204
S_3	$\frac{14}{14}$	$\frac{7}{12}$	$\frac{12}{16}$	$\frac{14}{10}$	162
Demand	82	204	82	123	

Table 7. Pay-off matrix

	Z_{nr}	Z_{dr}
X_{nr}	5177	6488
X_{dr}	5781	7426

Following Step 5, transform the objective functions into the constraints using the proposed transformation approach namely, neutrosophic aspirational approach. We can calculate the UB and LB for truth, indeterminacy and falsity MFs for the problem (G_3) and (G_4) based on [33].

Using the eqns (4) to (9) the formulation is given as follows:

(G_5) $Max\ \alpha - \beta + \gamma$

Subject to:

$10x_{11} + 27x_{12} + 10x_{13} + 13x_{14} + 14x_{21} + 16x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 7x_{32} + 12x_{33} + 14x_{34} \leq 5781 - \alpha\,(604)$

$10x_{11} + 27x_{12} + 10x_{13} + 13x_{14} + 14x_{21} + 16x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 7x_{32} + 12x_{33} + 14x_{34} \leq 5177 + s_{nr} - \beta\,(s_{nr})$

$10x_{11} + 27x_{12} + 10x_{13} + 13x_{14} + 14x_{21} + 16x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 7x_{32} + 12x_{33} + 14x_{34} \geq \gamma\,(604 - t_{nr}) + 5177 + t_{nr}$

$12x_{11} + 13x_{12} + 27x_{13} + 14x_{14} + 14x_{21} + 7x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 12x_{32} + 16x_{33} + 10x_{34} \geq \alpha\,(938) + 6488$

$12x_{11} + 13x_{12} + 27x_{13} + 14x_{14} + 14x_{21} + 7x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 12x_{32} + 16x_{33} + 10x_{34} \geq \beta\,(s_{dr}) + 6488$

$12x_{11} + 13x_{12} + 27x_{13} + 14x_{14} + 14x_{21} + 7x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 12x_{32} + 16x_{33} + 10x_{34} \leq 7426 - \gamma\,(938 - t_{dr})$

along with the constraints (1) – (3)

$\alpha \geq \gamma,\ \alpha \geq \beta,\ \alpha + \beta + \gamma \leq 3,\ \alpha, \beta, \gamma \in [0,1]$

By step 6, using the LINGO software, the above problem is solved to obtain the OCS. The optimal allocations

Table 6. Minimization function $z_{nr}(x)$ and Maximization function $z_{dr}(x)$

	Minimization function $z_{nr}(x)$					**Maximization function $z_{dr}(x)$**				
S_i \ D_j	D_1	D_2	D_3	D_4	Supply	D_1	D_2	D_3	D_4	Supply
S_1	10	27	10	13	123	12	13	27	14	123
S_2	14	16	14	13	204	14	7	14	13	204
S_3	14	7	12	14	162	14	12	16	10	162
Demand	82	204	82	123		82	204	82	123	

for the problem are as follows: The quantity of shipment of the electronic gadgets are 6 gadgets transported from Tamil Nadu to Hyderabad (i.e., $x_{11} = 6$), 82 gadgets from TN to Assam (i.e., $x_{13} = 82$), 35 gadgets from TN to Mumbai (i.e., $x_{14} = 35$), 76 gadgets from New Delhi to Hyderabad (i.e., $x_{21} = 76$), 40 gadgets from New Delhi to Gujarat (i.e., $x_{22} = 40$), 88 gadgets from New Delhi to Mumbai (i.e., $x_{24} = 88$), 162 gadgets from West Bengal to Gujarat (i.e., $x_{32} = 162$) and 2 gadgets from Karnataka to Gujarat (i.e., $x_{42} = 2$) and the rest are all zero. The obtained optimal compromise solution of transportation cost of electronic gadgets $Z_{nr}(x)$ is 5317 and transportation profit of electronic gadgets $Z_{dr}(x)$ is 7208. Hence, the neutrosophic OCS of the ratio of transportation cost to the profit of electronic gadgets is $\frac{(7103, 8989, 10164, 12229; 0.7, 0.4, 0.7)}{(10550, 12640, 14632, 17143; 0.6, 0.4, 0.7)}$

Based on DMs perception, if the above solution is not satisfied to the DMs expectation for each objective then go to Step 7.

Using Step 7, change the lower bound which lies between $6488 \le Z_{dr}(x) \le 7426$ and then repeat Step 5 to obtain the preferable solutions. Now we choose 6489 as a lower bound, then the problem (G_5) is changed to the problem (G_6),

(G_6) $Max\ \alpha - \beta + \gamma$

Subject to:

$10x_{11} + 27x_{12} + 10x_{13} + 13x_{14} + 14x_{21} + 16x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 7x_{32} + 12x_{33} + 14x_{34} \le 5781 - \alpha\,(604)$

$10x_{11} + 27x_{12} + 10x_{13} + 13x_{14} + 14x_{21} + 16x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 7x_{32} + 12x_{33} + 14x_{34} \le 5177 + s_{nr} - \beta\,(s_{nr})$

$10x_{11} + 27x_{12} + 10x_{13} + 13x_{14} + 14x_{21} + 16x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 7x_{32} + 12x_{33} + 14x_{34} \ge \gamma\,(604 - t_{nr}) + 5177 + t_{nr}$

$12x_{11} + 13x_{12} + 27x_{13} + 14x_{14} + 14x_{21} + 7x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 12x_{32} + 16x_{33} + 10x_{34} \ge \alpha\,(937) + 6489$

$12x_{11} + 13x_{12} + 27x_{13} + 14x_{14} + 14x_{21} + 7x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 12x_{32} + 16x_{33} + 10x_{34} \ge \beta\,(s_{dr}) + 6489$

$12x_{11} + 13x_{12} + 27x_{13} + 14x_{14} + 14x_{21} + 7x_{22} + 14x_{23} + 13x_{24} + 14x_{31} + 12x_{32} + 16x_{33} + 10x_{34} \le 7426 - \gamma\,(937 - t_{dr})$

along with the constraints (1) – (3)

$\alpha \ge \gamma,\ \alpha \ge \beta,\ \alpha + \beta + \gamma \le 3,\ \alpha, \beta, \gamma \in [0,1]$

Therefore, the obtained preferable solution to the above problem is $\frac{5317}{7208} = 0.737$. In the same manner, we can find the preferable solutions by changing the lower bound within the limits $6488 \le Z_{dr}(x) \le 7426$. Here, randomly some of the limits of lower bound are changed and the obtained preferable solutions are shown in Table 8.

The procedure is iterated until the best suitable OCS for the problem is attained. The obtained optimal compromise solution and the preferred solutions by using our proposed approach are depicted graphically in Figure 2.

Figure 2 depicts that the preferable solutions remains consistent between the range from 6488 to 6599. It increases with the increment of range from 6600 to 7400 and then slightly increases with an increment of range from 7401 to 7426. Our proposed approach provides the optimal compromise and preferable solutions which helps the flexibility to DMs by selecting their preferred solution from available choices based on their financial support.

As in Step 8, we calculate the sensitivity ranges of a_i and b_j for the actual values of a_i and b_j which are specified in Table 9.

From Table 9, we analyse that the solution remains optimal between the sensitivity ranges. If the limit exceeds or subceeds the obtained sensitivity ranges, then the solution is not optimal. This sensitivity ranges helps the DMs to identify that how much variations in the input values for a given variable impact the results for the problem.

Numerical Example 2

Every year, Global wind turbine companies transport windmill fans throughout the world. There are three manufacturing companies where the windmill fans can be transported from Suzlon Energy Ltd, Orient Green Power Ltd and Wind world India Ltd to the four customers namely, Jaisalmer, Dhule, Vaspet and Osmanabad. In order to increase the profit, windmill fans must be transported to every retailer in bulk. Due to various unforeseen factors like conditions of road, weather, traffic, price variations and so on, the parameters are considered as neutrosophic numbers. The yearly capacities of the windmill fans are $\tilde{a}_1^N$, $\tilde{a}_2^N$ and $\tilde{a}_3^N$ units and the yearly requirements of the windmill fans are $\tilde{b}_1^N$, $\tilde{b}_2^N$, $\tilde{b}_3^N$ and $\tilde{b}_4^N$ units respectively. Let us assume that the ratio of minimization of transportation cost $(\tilde{c}_{ij}^N)$ to

Table 8. Preferable solutions of lower bound within the limits $6488 \le Z_{dr}(x) \le 7426$

Limits of lower bound	Preferable solutions	Limits of lower bound	Preferable solutions
6488	$\frac{5317}{7208} = 0.737$	7400	$\frac{5733}{7403} = 0.774$
6489	$\frac{5317}{7208} = 0.737$	7426	$\frac{5781}{7426} = 0.778$
6600	$\frac{5329}{7217} = 0.738$		

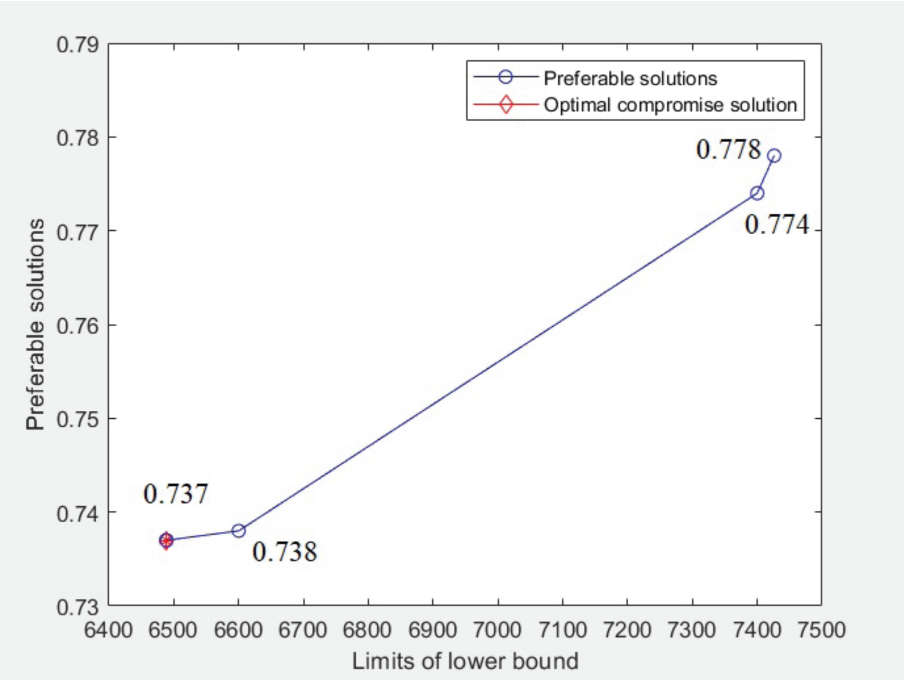

Figure 2. Graphical representation of obtained optimal compromise solution and preferable solutions.

Table 9. Sensitivity ranges of a_i and b_j

Values of a_i and b_j	**Sensitivity ranges of a_i and b_j**
$a_1 = 123$	$123 \le a_1^* < \infty$
$a_2 = 204$	$204 \le a_2^* < \infty$
$a_3 = 162$	$162 \le a_3^* < \infty$
$a_4 = 2$	$2 \le a_4^* < \infty$
$b_1 = 82$	$0.1 \le b_1^* \le 82$
$b_2 = 204$	$0.1 \le b_2^* \le 204$
$b_3 = 82$	$0.1 \le b_3^* \le 82$
$b_4 = 123$	$0.1 \le b_4^* \le 123$

Table 10. Neutrosophic transportation cost $(\tilde{c}_{ij}^N)$ to profit $(\tilde{p}_{ij}^N)$

S_i \ D_j	D_1	D_2	D_3	D_4	Supply
S_1	$\frac{\tilde{c}_{11}^N}{\tilde{p}_{11}^N}$	$\frac{\tilde{c}_{12}^N}{\tilde{p}_{12}^N}$	$\frac{\tilde{c}_{13}^N}{\tilde{p}_{13}^N}$	$\frac{\tilde{c}_{14}^N}{\tilde{p}_{14}^N}$	$\tilde{a}_1^N$
S_2	$\frac{\tilde{c}_{21}^N}{\tilde{p}_{21}^N}$	$\frac{\tilde{c}_{22}^N}{\tilde{p}_{22}^N}$	$\frac{\tilde{c}_{23}^N}{\tilde{p}_{23}^N}$	$\frac{\tilde{c}_{24}^N}{\tilde{p}_{24}^N}$	$\tilde{a}_2^N$
S_3	$\frac{\tilde{c}_{31}^N}{\tilde{p}_{31}^N}$	$\frac{\tilde{c}_{32}^N}{\tilde{p}_{32}^N}$	$\frac{\tilde{c}_{33}^N}{\tilde{p}_{33}^N}$	$\frac{\tilde{c}_{34}^N}{\tilde{p}_{34}^N}$	$\tilde{a}_3^N$
Demand	$\tilde{b}_1^N$	$\tilde{b}_2^N$	$\tilde{b}_3^N$	$\tilde{b}_4^N$	

the maximization of the profit $(\tilde{p}_{ij}^N)$ as the objective function to transport the windmill fans. The goal of the fractional TP is to reduce the transportation cost and increase the profit simultaneously. The problem (G_1) is modelled as fully SVTrN fractional TP where all the coefficients of transportation cost, profit, supply and demand constraints are shown in Table 10.

Supplies: $\tilde{a}_1^N = (14, 16, 21, 23; 0.9, 0.5, 0.3)$, $\tilde{a}_2^N = (31, 36, 42, 48; 0.8, 0.2, 0.1)$ and $\tilde{a}_3^N = (25, 30, 35, 36; 0.8, 0.2, 0.1)$

Demands: $\tilde{b}_1^N = (31, 35, 40, 45; 0.6, 0.4, 0.5)$, $\tilde{b}_2^N = (18, 20, 22, 29; 0.9, 0.1, 0.2)$, $\tilde{b}_3^N = (25, 30, 35, 40; 0.6, 0.2, 0.3)$ and $\tilde{b}_4^N = (14, 17, 21, 28; 0.9, 0.1, 0.1)$

Transportation cost:

$\tilde{c}_{11}^N = (10, 16, 18, 20; 0.5, 0.1, 0.1)$; $\tilde{c}_{12}^N = (5, 7, 9, 11; 0.9, 0.3, 0.2)$; $\tilde{c}_{13}^N = (14, 17, 21, 28; 0.5, 0.1, 0.2)$; $\tilde{c}_{14}^N = (14, 18, 20, 24; 0.3, 0.4, 0.5)$; $\tilde{c}_{21}^N = (14, 18, 20, 24; 0.3, 0.4, 0.5)$; $\tilde{c}_{22}^N = (14, 17, 21, 28; 0.5, 0.1, 0.2)$; $\tilde{c}_{23}^N = (3, 5, 6, 8; 0.5, 0.3, 0.2)$; $\tilde{c}_{24}^N = (10, 16, 18, 20; 0.5, 0.1, 0.1)$; $\tilde{c}_{31}^N = (14, 18, 20, 24; 0.3, 0.4, 0.5)$; $\tilde{c}_{32}^N = (3, 5, 6, 8; 0.5, 0.3, 0.2)$; $\tilde{c}_{33}^N = (10, 16, 18, 20; 0.5, 0.1, 0.1)$; $\tilde{c}_{34}^N = (4, 5, 6, 7; 0.7, 0.3, 0.1)$

Neutrosophic Profit:

$\tilde{p}_{11}^N = (3, 5, 6, 8; 0.5, 0.3, 0.2)$; $\tilde{p}_{12}^N = (4, 5, 6, 7; 0.7, 0.3, 0.1)$; $\tilde{p}_{13}^N = (10, 16, 18, 20; 0.5, 0.1, 0.1)$; $\tilde{p}_{14}^N = (5, 7, 9, 11; 0.9, 0.3, 0.2)$; $\tilde{p}_{21}^N = (10, 16, 18, 20; 0.5, 0.1, 0.1)$; $\tilde{p}_{22}^N = (4, 5, 6, 7; 0.7, 0.3, 0.1)$; $\tilde{p}_{23}^N = (5, 7, 9, 11; 0.9, 0.3, 0.2)$; $\tilde{p}_{24}^N = (14, 18, 20, 24; 0.3, 0.4, 0.5)$; $\tilde{p}_{31}^N = (14, 17, 21, 28; 0.5, 0.1, 0.2)$; $\tilde{p}_{32}^N = (4, 5, 6, 7; 0.7, 0.3, 0.1)$; $\tilde{p}_{33}^N = (4, 5, 6, 7; 0.7, 0.3, 0.1)$; $\tilde{p}_{34}^N = (14, 18, 20, 24; 0.3, 0.4, 0.5)$

Using Steps 2 to 6, the optimal allocations for the problem are as follows: The quantity of shipment of the windmill

Table 11. Comparison of the OCS of the solution approach using the proposed NAA with the existing approaches

		Solution approach using the proposed NAA	FPA [10]	FGPA [10]
Example 1	**Values of DV**	$x_{11} = 6$, $x_{13} = 82$, $x_{14} = 35$, $x_{21} = 76$, $x_{22} = 40$, $x_{24} = 88$, $x_{32} = 162$, $x_{42} = 2$	$x_{11} = 41$, $x_{13} = 82$, $x_{21} = 41$, $x_{22} = 40$, $x_{24} = 123$, $x_{32} = 162$, $x_{42} = 2$	$x_{11} = 41$, $x_{13} = 82$, $x_{21} = 41$, $x_{22} = 40$, $x_{24} = 123$, $x_{32} = 162$, $x_{42} = 2$
	OCS	$\frac{5317}{7208}=0.737$	$\frac{5177}{7103}=0.728$	$\frac{5177}{7103}=0.728$
	Preferable solutions	✓	×	×
Example 2	**Values of DV**	$x_{14} = 15$, $x_{21} = 6$, $x_{22} = 6$, $x_{23} = 12$, $x_{24} = 1$, $x_{31} = 8$, $x_{32} = 12$	$x_{14} = 15$, $x_{22} = 12$, $x_{23} = 12$, $x_{24} = 1$, $x_{31} = 14$, $x_{32} = 6$	$x_{14} = 15$, $x_{22} = 12$, $x_{23} = 12$, $x_{24} = 1$, $x_{31} = 14$, $x_{32} = 6$
	OCS	$\frac{116}{282}=0.41$	$\frac{140}{288}=0.48$	$\frac{140}{288}=0.48$
	Preferable solutions	✓	×	×

Note: *DV- Decision variable, *OCS-Optimal compromise solution, *FPA-Fuzzy programming approach, *FGPA- Fuzzy goal programming approach

fans are 15 fans are transported from Suzlon energy ltd to Osmanabad (i.e., $x_{14} = 15$), 6 fans from Orient green power ltd to Jaisalmer (i.e., $x_{21} = 6$), 6 fans from Orient green power ltd to Dhule (i.e., $x_{22} = 6$), 12 fans from Orient green power ltd to Vaspet (i.e., $x_{23} = 12$), 1 fan from Orient green power ltd to Osmanabad (i.e., $x_{24} = 1$), 8 fans from wind world India ltd to Jaisalmer (i.e., $x_{31} = 8$), 12 fans from wind world India ltd to Dhule (i.e., $x_{32} = 12$) and the rest are all zero. The obtained optimal compromise solution of transportation cost of windmill fans $Z_{nr}(x)$ is 116 and transportation profit of windmill fans $Z_{dr}(x)$ is 282. Hence, the neutrosophic OCS of the ratio of transportation cost to the profit of windmill fans is $\frac{(572, 760, 868, 1076; 0.3, 0.4, 0.5)}{(393, 529, 647, 791; 0.3, 0.4, 0.5)}$

Comparative Analysis

Table 11 presents the results of optimal compromise solution (OCS) obtained using various optimization methods such as neutrosophic aspirational approach (NAA), fuzzy programming approach (FPA) [10] and fuzzy goal programming approach (FGPA) [10]. These methods were applied to the same numerical example to compare their results with the goal of evaluating the effectiveness of each approach to achieve the optimal results. The study demonstrates that NAA attains competitive values of objective function and obtains almost the same result as FPA and FGPA.

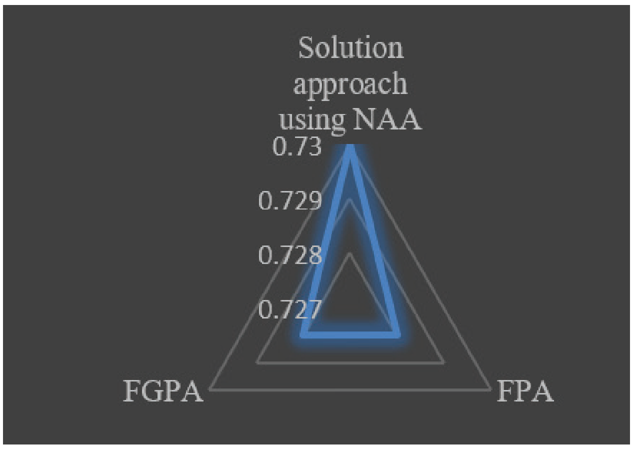

Figure 3. Comparison between the proposed NAA and the existing approaches for Example 1.

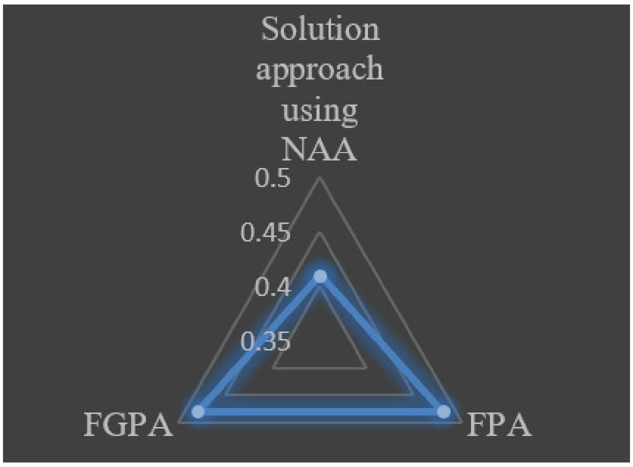

Figure 4. Comparison between the proposed NAA and the existing approaches for Example 2.

The OCS is calculated by dividing the value of numerator by the denominator obtained by NAA, FPA and FGPA. For better understanding, the comparison of obtained OCS for Examples 1 and 2 of the solution approach using the proposed NAA and the existing approaches is illustrated in Figures 3 and 4 respectively.

From Table 11, Figures 3 and 4, it can be concluded that the solution approach using the proposed NAA for Example 1 provides OCS that are closer when compared to FPA and FGPA and for Example 2, the obtained OCS of the solution approach using the proposed NAA provides better result than FPA and FGPA. The inclusion of neutrosophic parameters in our proposed approach increases the accuracy of the obtained solution. When DMs are selecting windmill fans, one may opt for a more cost-effective option with lower long-term energy generation, while another might prioritize a higher initial investment for better long-term benefits. In these situations, our proposed approach provides the optimal compromise and preferable solutions. The preferable solutions for the problem is shown in Table 8. This helps the DMs to select their windmill fans using the preferable solution whereas the other existing approaches provide only the optimal compromise solution.

CONCLUSION

This study explores the neutrosophic fractional transportation problem by simultaneously optimizing both transportation cost and profit. To transform the neutrosophic problem into its deterministic problem, the weighted possibility mean is applied. In the need of windmill fans for the decision makers, the roles of objective functions and constraints can change in the design, manufacturing and operating wind turbines based on factors such as regulatory changes, market conditions, resource availability and customer priorities. By adjusting these roles ensures that design, production and operation of windmill fans remain competitive and effective in a dynamic environment. So, the neutrosophic aspirational approach is proposed, which serves as a novel aspect of this paper, to convert the objective function into constraints. To demonstrate the effectiveness and superiority of the proposed approach, we have illustrated two numerical examples and solved to obtain the optimal compromise solution. In addition to this, we obtain the preferable solutions by changing the lower bound in the problem using our proposed approach which helps the decision makers for site characteristics such as weather patterns, land availability, optimal wind speed, minimal environmental disruption and high efficiency. It also allows to change the production costs, maintenance costs and operational costs of the windmill fans. To enhance the efficiency of the problem, the obtained solution assist the decision maker in making the right choices regarding financial and corporate planning. This study examines the neutrosophic single objective fractional transportation problem by minimizing the transportation cost and maximizing the profit. In real world, many decision-making problems can be described as multi-objective optimization problems since numerous competing objectives may be achieved at the same time. In view of this for future research, one may consider multi-objective four dimensional fixed charge fractional transportation problem under neutrosophic environment, neutrosophic multi-item multi-objective four dimensional fixed charge fractional transportation problem, neutrosophic multi-level multi-item multi-objective four dimensional fixed charge fractional transportation problem and neutrosophic multi-stage multi-objective four dimensional fixed charge fractional transportation problem. In addition to transportation problem, this approach may also be applied to the assignment problem and the travelling salesman problem.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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