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Pythagorean fuzzy transportation problem: New way of ranking for Pythagorean fuzzy sets and mean square approach

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ABSTRACT

The predominant domain for optimization in the current situation is the transportation problem (TP). In the majority of cases, accurate data have been employed, yet in reality, the values are vague and imprecise. In any decision-making process, imprecision is a significant issue. To deal with the ambiguous setting of collective decision-making, many tools and methods have been established. The Pythagorean fuzzy set is an extension of fuzzy sets that successfully handles ambiguity and fuzziness. To overcome the shortcomings of intuitionistic fuzzy context, Pythagorean fuzzy sets are considered to be the most recent tools. This study proposes a new method for addressing the uncertain Pythagorean transportation issue. In this study, we created a novel sorting technique for Pythagorean fuzzy sets that converts uncertain quantities into crisp numbers. We developed an innovative mean square strategy for obtaining the initial basic feasible solution (IBFS) for a Pythagorean Fuzzy Transit Issue (PyFTP) of three types (I, II, III) wherein the requirement, availability, and unit of transportation expenses are all in Pythagorean uncertainty. In addition, we used the MODI technique to find the best option. To demonstrate the suggested strategy, we used numerical problems of three distinct kinds. A comparison table with the results of the previous strategy and the suggested method is created to state the benefits of the ranking methodology with the proposed algorithm. The discussion of future research and conclusions is the final step.

1. Introduction

A specific sort of linear programming problem is the transportation problem. The transportation problem seeks to lower the price of a specific good from a number of suppliers to a variety of destinations. Each source has a finite amount to supply, and each destination has a demand that needs to be met [1]. The quantity of units delivered directly relates to the cost of transport from a source to its destination. One of the key mechanisms for effectively delivering goods to customers is the transportation engine. The issue with transportation is the dropping in the price of goods to customers more effectively. The necessary progression and cautious usability of raw materials and completed goods are provided by the transportation problems. The goal of the transportation issue is to enhance revenue or reduce expenses [2].

Numerous practical applications include major transportation-related issues. Transversal costs of demand and availability are previously assumed to be stated in terms of precise figures. These values, however, are typically ambiguous or imprecise [3]. As a

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result, academics have tried a number of different approaches to solving various transportation issues in the fuzzy environment [4].

In some real-world circumstances, we tend to look for the maximum or minimal, ideal answers to the issues at hand. Uncertainty theory was developed as a result of the fact that the data that need to be managed are typically ill-defined, unpredictable, and imprecise. For of its several applications across various divisions of network stream problems, manufacturing, shortest path concern picks up supply chain issues, travel salesman problems, and traffic assignment problems, fuzzy optimization has grown significantly in prominence among many researchers in the last few decades [5].

While classical groups are utilized aimed at clarity, the idea of an uncertain set is established to deal with ambiguity. Zadeh [6] became familiar with the fuzzy set paradigm. Zadeh argued about the membership component, also referred to as the membership degree, from the concept of the fuzzy set. It permits partial membership in the collection of items. In addition, Zadeh developed a wide range of applications for fuzzy set theory in several fields, including code for computers, engineering, management academia, etc. The appraisal of membership is insufficient in their opinion due to the inadequate information available [7]. Extensions like Intuitionistic Fuzzy Sets (IFS) and Pythagorean Fuzzy Sets (PFS) have been created in an attempt to overcome inadequacies in the fuzzy system concept [8].

Atanassov [9] was the one who originally proposed IFS, a generalization of Zadeh's concept of fuzzy notion. Each component of the IFS is described by an ordered pair (μ, ν) that meets the requirement $\mu + \nu \leq 1$. The application of IFS to real-world situations involving decision-making using multiple attributes has seen tremendous academic advancement in this area. Contrary to the examples recorded in IFSs, there are instances where $\mu + \nu \geq 1$. This IFS constraint prompted the development of a concept known as Pythagorean fuzzy sets (PFSs). PFSs serve as a useful advancement of the IFS, which were first suggested by Yager [10] as a generalization of fuzzy concepts. By taking into the level of association degree and non-association degree fulfilling the requirements $\mu + \nu \leq 1$ or $\mu + \nu \geq 1$, the PFS provides a new approach to deal with ambiguity. The PFS is further distinguished by affiliated and unaffiliated degrees, the sum of which is less than or equal to one [11–13]. It also indicates that $\mu^2 + \nu^2 + \pi^2 = 1$, in which π is the Pythagorean fuzzy set index [14]. For illustrating the ambiguity of issues involving multiple attribute decision-making (MADM), the Pythagorean fuzzy model is a great aid. PFSs are useful in a wide range of fields [15].

Paul Augustine Ejegwa [16], who worked on the derivation of a few theorems relating to the scoring and accuracy functions of Pythagorean fuzzy sets, addresses a decision-making technique for professional placements based on academic effectiveness. The Pythagorean fuzzy connection is viewed as a max-min-max construct in this approach for evaluating the acceptability of job applications. Rahman et al. [17] devised and employed the interval-valued Pythagorean fuzzy-weighted geometrically aggregating methodologies to address several attribute decision-making challenges. Kumar et al. [18] filled the gaps in the literature by developing a unique accuracy formula for Interval-Valued Pythagorean Fuzzy Collections. Four crucial membership, non-membership, intensity, and direction of commitment criteria were included to achieve this. Harish Garg [19] suggested a better scoring way for the proper sequence of elapsed time PFS. As a result of its foundation, the TOPSIS technique, a Pythagorean uncertain approach for ordering preferences by similarity to the ideal solution, was created, which incorporates expert recommendations as interval-valued intuitionistic Pythagorean fuzzy decision matrices. Shu-Ping Wan et al. [20] devised a novel system for evaluating Pythagorean fuzzy numbers (PFNs). First, two metrics—knowledge measure and information reliability—are suggested to assess the quantity and quality of the information, respectively. Second, a relative intimacy degree based on arc length is offered, inspired by TOPSIS. PFNs are to be rated using the extended relative intimacy degree, information dependability, and a novel ranking mechanism. Muhammed Akram et al. [21] extended the TOPSIS technique to address multicriteria group decision-making difficulties with Pythagorean uncertainty, where the assessment data on possible alternatives gathered from experts appears as Pythagorean fuzzy decision matrices with all entries characterized by Pythagorean fuzzy values. Moreover, for the ranking of the options and the determination of the best selection utilized a revised closeness index.

To solve the drawbacks of an intuitionistic fuzzy digraph (IFDG), Mani Parimala et al. [22] created the Pythagorean fuzzy digraph (PyFDG). It deals with inaccurate arc weights, including a level of acceptance and a degree of refusal. To address application issues in healthcare facilities, PyFDG, as well as its essential process and scoring measure, have been designed. Harpreet Kaur [23] brought up a novel approach using PFN to address the Job Sequencing problem. To overcome the issue of uncertainty in crisp job scheduling situations, an approach is suggested. Amit Kumar [24] invented the Mehar Scoring function as a new composition to find the best answer to dual-hesitant unclear transportation circumstances. It transforms a dual hesitant hazy idea into a precise number. Mahmood and Ur Rehman [25] proposed a new method for bipolar complex fuzzy sets including its implementation in generalized similarity metrics. Kifayat Ullah et al. [26] created several distant measurements of complex Pythagorean fuzzy sets and applied them to a building material recognition issue. For the development of new products, Goçer and Büyükozkan [27] developed an innovative extension of the Pythagorean fuzzy Multi-objective Optimization by Ratio Analysis (MULTIMOORA) technique.

Initially, Kumar et al. [28] offered a new algorithmic approach to handling the Pythagorean fuzzy transportation issue (PyFTP). However, they offered three distinct frameworks in a Pythagorean uncertain setting, each of which included the mathematical and numerical requirements of Pythagorean fuzzy computing. For PFN, Umamageswari and Uthra [29] developed an average ranking method, while for PyFTP, they employed the VAM method. Jayapriya and Sophia Porchelvi [30] made an effort to provide a variety of Pythagorean fuzzified and defuzzified functions to imitate real-world circumstances in the Pythagorean uncertain environment. Later, Divya Bharathi and Kanmani [31] introduced a new PyFTP algorithm and demonstrated that their suggested methods provided the best answer. They employed an existing score function when developing an algorithm for their investigation. Sathya Geetha and Selvakumari [32] presented a simultaneous moving approach designed for the Pythagorean uncertain transportation issue. This method uses fewer iterations to achieve the best answer. Saranya and Charles Rabinson [33] created an optimum PyFTP technique for decagonal numbers. Priyanka Nagar et al. [34] created a technique which decreases the likelihood of losing any kind of information while still providing the best solution in fuzzy form. Krishna Prabha et al. [35] developed a geometric mean approach to tackle a

PyFTP. Laxminarayan Sahoo [36] developed three new score algorithms for ranking transportation-related concerns using Fermatean imprecise variables. Jeyalakshmi et al. [37] approached a PyFTP using the Monalisha approximation technique.

This study aims to address transportation issues where supply, demand, and transportation prices are PFN. The primary goal of this research is to reduce total transport expenses in a Pythagorean fuzzy context. Based on the prior discussions, there are no parallel fresh approaches for both ranking and IBFS to resolve TP in a Pythagorean uncertain setting. This research gap led the authors to develop a novel ranking and IBFS technique that can optimize the transportation problem in a Pythagorean uncertain context. This paper's key contribution is as follows:

(i) We suggested a new ranking for PFS.
(ii) We developed a mean square strategy to achieve the initial fundamental workable solution of PyFTP.
(iii) We considered numerical examples of three types (I, II, III) to show the effectiveness of proposed algorithm and then we compared our method with existing ones.

The following are the anticipated steps for this research: preliminaries and their mathematical operations are reported in the succeeding section, Section 3 develops a mathematical design for the PyFTP, Section 4 proposes a method to obtain IBFS, and Section 5 presented practical examples. In Section 6, the results and discussion are presented, and in Section 7, the conclusion and future research are covered.

2. Preliminaries

The fundamental descriptions of IFS and PFS that we employed in our work are presented in this section.

Definition 2.1. Intuitionistic fuzzy set [38].

Below is the description of the IFS, a fuzzy set expansion that Atanassov developed:

Let $\dot{X}$ represent the universe. The following is the definition of an IFS $\mathring{A}$:

$\mathring{A} = \{\langle \mathfrak{x}, \boldsymbol{\mu}_{\mathring{A}}(\mathfrak{x}), \boldsymbol{\nu}_{\mathring{A}}(\mathfrak{x})\rangle \mid \mathfrak{x} \in \dot{X}\}$

here $\boldsymbol{\mu}_{\mathring{A}}: \dot{X} \rightarrow [0,1]$ signifies the membership level and

$\boldsymbol{\nu}_{\mathring{A}}: \dot{X} \rightarrow [0,1]$ signifies the level of non-membership of the component $\mathfrak{x} \in \dot{X}$ to the set $\mathring{A}$, accordingly, provided that $0 \leq \boldsymbol{\mu}_{\mathring{A}}(\mathfrak{x}) + \boldsymbol{\nu}_{\mathring{A}}(\mathfrak{x}) \leq 1$, and the level of unpredictability is

$$\pi_{\mathring{A}}(\mathfrak{x}) = 1 - \mu_{\mathring{A}}(\mathfrak{x}) - \nu_{\mathring{A}}(\mathfrak{x}).$$

Definition 2.2. Pythagorean Fuzzy Set [18].

Let $\dot{X}$ be a discourse universe. In $\dot{X}$, a PFS Ᵽ is described by

$$Ᵽ = \{(\mathfrak{x}, \mu_{Ᵽ}(\mathfrak{x}), \nu_{Ᵽ}(\mathfrak{x})) \mid \mathfrak{x} \in \dot{X}\}$$

where $\mu_{Ᵽ}: \dot{X} \rightarrow [0,1]$ signifies the association level and.

$\nu_{Ᵽ}: \dot{X} \rightarrow [0,1]$ signifies the level of non-association of the component $\mathfrak{x} \in \dot{X}$ to the set Ᵽ, accordingly, provided that $0 \leq (\mu_{Ᵽ}(\mathfrak{x}))^2 + (\nu_{Ᵽ}(\mathfrak{x}))^2 \leq 1$ and the level of unpredictability is.

$\pi_{Ᵽ}(\mathfrak{x}) = \sqrt{1 - (\mu_{Ᵽ}(\mathfrak{x}))^2 - (\nu_{Ᵽ}(\mathfrak{x}))^2}$. This is displayed below in Fig. 1.

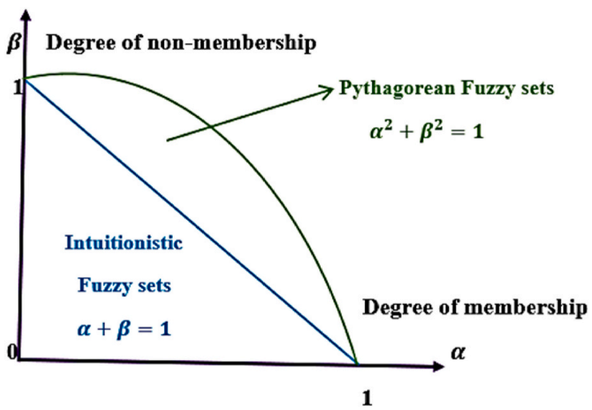

Fig. 1. Visual representation of IFS and PFS.

Definition 2.3. [28]

Let $\sigma = (\mu_1^p, \nu_1^p)$ and $\varphi = (\mu_2^p, \nu_2^p)$ are two Pythagorean Fuzzy Numbers (PFNs). The following are the mathematical operations that can be performed on PFNs:

(i) Addition: $\sigma \oplus \varphi = (\sqrt{(\mu_1^p)^2 + (\mu_2^p)^2 - (\mu_1^p)^2 \cdot (\mu_2^p)^2}, \nu_1^p \cdot \nu_2^p)$;

(ii) Multiplication: $\sigma \otimes \varphi = (\mu_1^p \cdot \mu_2^p, \sqrt{(\nu_1^p)^2 + (\nu_2^p)^2 - (\nu_1^p)^2 \cdot (\nu_2^p)^2})$;

(iii) Scalar component: $k \cdot \sigma = (\sqrt{1 - (1 - \mu_1^p)^k}, (\nu_1^p)^k)$, where k signifies a constant which is not negative ($k > 0$)

Definition 2.4. Proposed technique of ranking

Let $Ᵽ = (\mu_Ᵽ(x), \nu_Ᵽ(x))$ be a Pythagorean fuzzy number. The ranking function is a defuzzification tool of Pythagorean fuzzy numbers to crisp numbers. It is used to compare fuzzy numbers. The following definition in equation (1) defines the new ranking approach of Ᵽ on the set of Pythagorean fuzzy numbers:

$$R(Ᵽ) = \frac{(\mu_Ᵽ)^2 + (\nu_Ᵽ)^2 - [|\mu_Ᵽ - \nu_Ᵽ|]^2}{2} \tag{1}$$

Based on the new rank function we can analyse two PFNs. If $\sigma = (\mu_1^p, \nu_1^p)$ and $\varphi = (\mu_2^p, \nu_2^p)$ are two PFNs, then the relation between those are given by,

Case (1). $\sigma > \varphi$ iff $R(\sigma) > R(\varphi)$

Case (2). $\sigma < \varphi$ iff $R(\sigma) < R(\varphi)$

Case (3). $\sigma = \varphi$ iff $R(\sigma) = R(\varphi)$

3. Mathematical expression of Pythagorean fuzzy transportation problem

Let us think about “m" sources and “n" locations. The distribution system aims to decrease the cost of transporting items from these suppliers to the regions, however, the availability and demand of the commodities are specified with the following assumptions and limitations. Table 1 represents the notations for crisp transportation model and Pythagorean fuzzy transportation model.

m - number of supplies in the system as a whole.
n - number of receiving nodes overall.
i- index of whole sources in m
j - total destination index for n
$x_{ij}-$ quantity of products moved from source to destination in units

The mathematical description of the PyFTP is then as follows in equations (2)–(4) and represented in Table 2.

$$\text{Minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \cdot C_{ij}^{Ᵽ} \tag{2}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = a_i^{Ᵽ}, \tag{3}$$

$$\sum_{i=1}^{m} x_{ij} = b_j^{Ᵽ}, \tag{4}$$

$$x_{ij} \geq 0 \forall i, j$$

Table 1
Notations for Pythagorean fuzzy transportation model.

Transportation Model	Pythagorean Fuzzy Transportation Model
C_{ij} - A charge for each unit of Crisp.	$C_{ij}^{Ᵽ}$- Transferring one unit of a specified amount from supplier to recipient at the Pythagorean imprecise expense.
a_{ij} - The amount of resource that is readily available from each source in the crisp environment.	$a_{ij}^{Ᵽ}$ - The amount of supply that is readily available from each source in the Pythagorean imprecise setting.
b_{ij} - The quantity that the market demands from each destination in a crisp environment.	$b_{ij}^{Ᵽ}$- The amount that each destination's market requires in the Pythagorean imprecise setting.

Table 2
Pythagorean fuzzy transportation problem.

		Destinations				
		$\mathcal{D}1$	$\mathcal{D}_2$	....	$\mathcal{D}_n$	Supply
Sources	Q_1	c_{11}^{P}	c_{12}^{P}	....	c_{1n}^{P}	a_1^{P}
	Q_2	c_{21}^{P}	c_{22}^{P}	....	c_{2n}^{P}	a_2^{P}
	....	....	....	....	....	....
	Q_m	c_{m1}^{P}	c_{m2}^{P}	....	c_{mn}^{P}	a_m^{P}
	Demand	b_1^{P}	b_1^{P}	....	b_1^{P}	

4. Algorithm for Pythagorean fuzzy transportation model

The steps of the proposed PyFTP are described below.

Step 1. Select the Pythagorean fuzzy transport problem.

Step 2. Using the suggested ranking method in equation (1), determine the crisp value of every cost matrix, demand, and supply of the selected PyFTP.

Step 3. Test the balance of the provided PyFTP.

(i) Go to step 5 if it is balanced (i.e., total supply equals total demand).
(ii) Go to step 4 if it is not balanced (i.e., total supply $\neq$ total demand).

Step 4. Create dummy rows or dummy columns with zero Pythagorean fuzzy costs to achieve a balanced one.

Step 5. Each row's cost matrix is added, and the added costs of each row are divided by the number of columns.

Step 6. Each column's matrix is added, and the added costs of each column are divided by the number of rows.

Step 7. Square the values obtained for each row and column after steps 5 and 6.

Step 8. Now determine the highest squared value between the row and column. If the maximum value is the same for both the row and the column, choose either one (that is, the row or the column).

Step 9. Examine the cell in the corresponding row or column that has the lowest cost.

Step 10. Determine the minimum between supply and demand value, and place it in the least expensive cell.

Step 11. Eliminate the entire row or column after allocation is finished for either row or column.

Step 12. Continue with steps 5 to 11 until all the demand and supply have been assigned in order to get the initial basic feasible solution, and then use the MODI approach to determine the optimal solution.

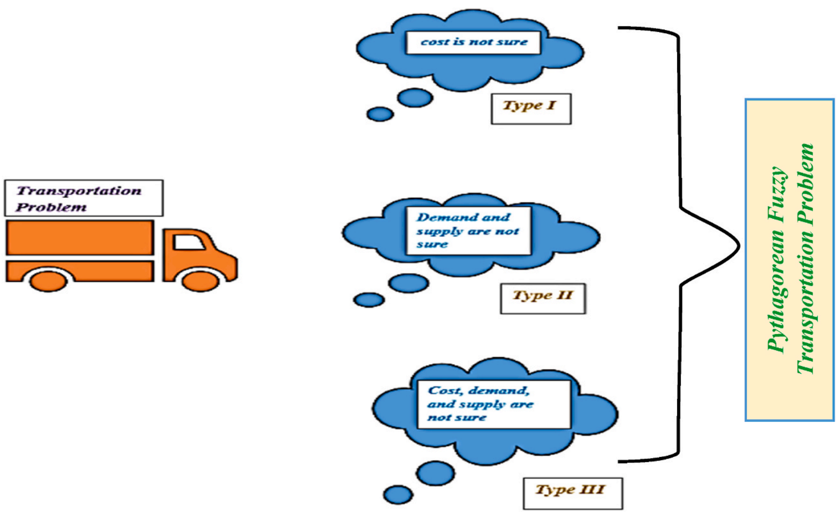

Fig. 2. Different types of PyFTP.

5. Numerical example

The problems below serve as illustrations of the various PyFTP kinds shown in the above Fig. 2.

5.1. Type I [28]

An oil company has three refineries and must deliver fuel to four distinct depots. Pythagorean fuzzy data are used to signify the price of transporting one unit of gasoline from each refinery to each depot shown in Table 3. Calculate the least expensive overall transportation cost.

The suggested algorithm's operational process is shown in Tables 4–8.

After achieving IBFS of the suggested method and moving on with this allocation using the MODI method, we obtain the Pythagorean fuzzy minimum transportation cost, which is 11.76.

Table 3
Data for the Pythagorean fuzzy transportation problem of type I [28].

	A	*B*	*C*	*D*	Availability
K_1	(0.4,0.7)	(0.5,0.4)	(0.8,0.3)	(0.6,0.3)	26
K_2	(0.4,0.2)	(0.7,0.3)	(0.4,0.8)	(0.7,0.3)	24
K_3	(0.7,0.1)	(0.8,0.1)	(0.6,0.4)	(0.9,0.1)	30
Requirement	17	23	28	12	

Table 4
First allocation of defuzzified values.

	A	*B*	*C*	*D*	Availability	Row Penalty
K_1	0.28	0.20	0.24^{26}	0.18	26	0.05
K_2	0.08	0.21	0.32	0.21	24	0.04
K_3	0.07	0.08	0.24	0.09	30	0.014
Requirement	17	23	28	12	80	
Column Penalty	0.020	0.026	0.070	0.0256		

Table 5
Second allocation.

	A	*B*	*C*	*D*	Availability	Row Penalty
K_2	0.08	0.21	0.32	0.21	24	0.04
K_3	0.07	0.08	0.24^{2}	0.09	30	0.014
Requirement	17	23	2	12		
Column Penalty	0.0056	0.021	0.070	0.0225		

Table 6
Third allocation.

	A	*B*	*D*	Availability	Row Penalty
K_2	0.08^{17}	0.21	0.21	24	0.0275
K_3	0.07	0.08	0.09	28	0.0064
Requirement	17	23	12		
Column Penalty	0.0056	0.021	0.0225		

Table 7
Fourth allocation.

	B	*D*	Availability	Row Penalty
K_2	0.21	0.21^{7}	7	0.0441
K_3	0.08	0.09	28	0.0072
Requirement	23	12		
Column Penalty	0.021	0.0225		

Table 8
Final allocations.

	B	D	Availability	Row Penalty
K_3	0.08 [23]	0.09 [5]	28	0.0072
Requirement	23	5		
Column Penalty	0.0064	0.0081		

Table 9
Information on type II Pythagorean Fuzzy Transportation Problem [28].

	R_1	R_2	R_3	R_4	Availability
P_1	0.0335	0.0545	0.0775	0.0635	(0.7,0.1)
P_2	0.056	0.07	0.026	0.07	(0.8,0.1)
P_3	0.074	0.0815	0.06	0.09	(0.9,0.1)
Requirement	(0.4,0.7)	(0.7,0.3)	(0.8,0.1)	(0.60832,0.4)	

5.2. Type II [28]

A petroleum firm must deliver fuel to four distinct depots from its three refineries. The price of delivering one unit of gasoline from each refinery to each depot is specified in crisp form shown in Table 9. Calculate the lowest possible transportation expense.

Once demand and supply have been defuzzified using step 2, determine if the table is balanced or not. If it is not balanced, create a dummy row or column, and proceed with the allocation using the suggested technique until demand and supply are distributed equally. The ideal solution of minimum PyFT (Pythagorean Fuzzy Transportation) cost is then determined by employing the MODI approach, and it is 0.011085.

5.3. Type III [28]

An oil company has three refineries and must deliver fuel to four distinct depots. Pythagorean fuzzy data are used to signify demand, supply, and the cost of moving one unit of gasoline from each refinery to each depot shown in Table 10. Calculate the lowest possible transportation expense.

Using the recommended method for IBFS and the MODI technique, we arrive at the optimal solution of Pythagorean fuzzy minimum transportation cost, which is 0.013592.

Table 10
Type III Pythagorean fuzzy transportation problem data [28].

	1	2	3	4	Availability
Q	(0.1,0.9)	(0.2,0.8)	(0.1,0.8)	(0.1,0.9)	(0.7,0.1)
R	(0.01,0.99)	(0.3,0.9)	(0.3,0.9)	(0.1,0.7)	(0.8,0.1)
S	(0.1,0.8)	(0.4,0.8)	(0.4,0.9)	(0.2,0.9)	(0.9,0.1)
Requirement	(0.4,0.7)	(0.7,0.3)	(0.8,0.1)	(0.60832,0.4)	

Table 11
Input Values for type I PyFTP.

	i	J	k	l	Availability
1	(0.7,0.3)	(0.6,0.5)	(0.4,0.5)	(0.6,0.3)	42
2	(0.8,0.4)	(0.5,0.5)	(0.9,0.2)	(0.7,0.4)	36
3	(0.5,0.7)	(0.9,0.1)	(0.8,0.1)	(0.8,0.4)	48
4	(0.6,0.3)	(0.4,0.6)	(0.5,0.4)	(0.5,0.7)	20
Requirement	30	38	45	33	

Table 12
Input Values for type II PyFTP.

	M_1	M_2	M_3	M_4	Availability
S	20	25	32	30	(0.2,0.7)
T	48	40	52	42	(0.6,0.5)
U	60	73	79	83	(0.6,0.4)
Requirement	(0.7,0.4)	(0.8,0.4)	(0.5,0.6)	(0.6,0.6)	

Table 13
Input Values for type III PyFTP.

	G	*H*	*I*	Availability
O_1	(0.5,0.4)	(0.6,0.5)	(0.7,0.2)	(0.2,0.7)
O_2	(0.8,0.3)	(0.7,0.2)	(0.9,0.1)	(0.6,0.5)
O_3	(0.3,0.6)	(0.8,0.4)	(0.7,0.5)	(0.6,0.4)
Requirement	(0.7,0.4)	(0.8,0.4)	(0.5,0.6)	

5.4.

A transportation issue involving four warehouses and four consumers is presented below. We need to figure out the lowest overall transport expense for the following Table 11.

Transform Pythagorean uncertain numbers to a crisp by applying a new ranking method. Following that, we achieved IBFS employing the provided technique, and the optimal transit cost is 22.19.

5.5.

A bicycle manufacturer has three manufacturing plants and must supply goods to four terminals. We must determine the lowest possible transport price for delivering items for the given Table 12.

The optimal transit cost using the proposed technique is 30.1.

5.6.

We have to figure out an ideal solution to the subsequent transportation issue for Table 13, which contains three warehouses and three terminals.

The optimal transit cost using the proposed technique is 0.0968.

6. Results and discussion

Based on the worked-out numerical instances of the preceding part, we can conclude that both the prescribed ranking procedure and the novel algorithm produce improved outcomes. To ensure the accuracy of the approach that was suggested, we employed randomly numerical scenarios of three distinct kinds, in addition to the previous values. In Tableau 14, we examined our strategy to two existing approaches. The ranking techniques utilized in these two previous approaches varied, however, Vogel's approximation approach was used to solve PyFTP. In the present work, a novel ranking method and novel algorithm were applied. The outcomes enable us to conclude that the ranking strategy significantly contributes to cost minimization. Furthermore, when compared to previous approaches, the algorithm we developed produces better outcomes. The reduction of overall expenses for transportation is the goal of this article. By using the prescribed technique, we succeeded in our goal. The impact of each method on both pre-existing data and randomly generated data is displayed in Fig. 3(a–c) below.

Table 14
Comparison of existing techniques.

		Existing Data	
Examples	**Types**	**Existing method** [28]	**Proposed Method**
5.1	I	41.45	11.76
5.2	II	0.132978	0.011085
5.3	III	0.31895	0.013592
		Existing method [29]	**Proposed method**
5.1	I	27.48	11.76
5.2	II	0.050195	0.011085
5.3	III	0.31105	0.013592
		Random Data **Existing methods** [28,29]	**Proposed method**
5.4	I	22.27	22.19
5.5	II	31.06	30.1
5.6	III	0.1348	0.0968

Fig. 3. Comparative Chart; (a), (b) Existing values, Proposed method compared with Existing methods, and (c) Random values, Proposed method compared with Existing methods.

7. Conclusion and future studies

The current work optimizes the Pythagorean Fuzzy Transportation Issue, a particular family of uncertain transportation issues. In this article first we introduced a novel ranking strategy for Pythagorean fuzzy collections that is more trustworthy than the current ranking formula. Second, we developed an innovative algorithm to arrive an initial basic workable solution for addressing challenges with transportation in a Pythagorean uncertain setting. The demonstration of the above method to six numerical instances did not reveal any flaws in the technique and achieved the objectives of this proposed study. The efficiency of the suggested algorithms has been evaluated by analyzing the existing methods. The recommended algorithm presents a novel method for handling uncertainty. This demonstrates the value and potency of our suggested algorithm. The ranking method that was suggested can be used to tackle Pythagorean assignment issues and Pythagorean transshipment challenges, and decision-makers can utilize it to address real-world transportation challenges. Further, it shows that decision-making issues including ambiguity can be successfully resolved using the suggested technique. We will expand this work to spherical fuzzy sets in subsequent studies. Information that combines real and imaginary components cannot be solved by the presented technique. From the preceding statement, we conclude that our suggested ranking technique is unable to resolve complex fuzzy sets, bipolar complex fuzzy context, and complex Pythagorean uncertainty, on which we will focus in the future.

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Data availability statement

Data will be made available on request.

Ethical approval

The creation of this work did not include any people or animals.

CRediT authorship contribution statement

Hemalatha K: Conceptualization, Methodology, Writing – original draft. **Venkateswarlu B:** Conceptualization, Methodology, Supervision, Validation, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] T. Benith Sowmya, K. Selvakumari, On solving fuzzy transportation problem using fuzzy one point method, Int. J. Mech. Eng. 7 (No.2) (2022).
[2] M. Palanivel, M. Suganya, A new method to solve transportation problem - harmonic mean approach, Eng. Technol. 2 (3) (2018), 555586, https://doi.org/10.19080/ETOAJ.2018.02.555586.
[3] Haridas Roy, et al., A study of fuzzy transportation problem using zero-point method with ranking of trapezoidal fuzzy numbers, Bulletin Monumental - ISSN/e-ISSN 0007-473X 21 (Issue 08) (2020).
[4] R.R. Yager, Pythagorean fuzzy subsets, in: Proceedings of the Joint IFS World Congress NAFIPS Annual Meeting, 2013, pp. 57–61.
[5] Xindong Peng, Yong Yang, Some results for pythagorean fuzzy sets, Int. J. Intell. Syst. 30 (2015) 1133–1160.
[6] L.A. Zadeh, Fuzzy Sets, Information and Computation 8 (1965) 338–353.
[7] I. Silambarasan, S. Sriram, Some new results on pythagorean fuzzy matrices, IOP Conf. Series: J. Phys. Conf. 1344 (2019), 012042, https://doi.org/10.1088/1742-6596/1344/1/012042.
[8] R.R. Yager, Pythagorean membership grades in multicriteria decision making, in: Technical Report MII-3301, Machine Intelligence Institute, Iona College, New Rochelle, 2013.
[9] K.T. Atanassov, Intuitionistic fuzzy sets, Fuzzy sets Syst 20 (1986) 87–96.
[10] R.R. Yager, Pythagorean membership grades in multicriteria decision making, IEEE Trans. Fuzzy Syst. 22 (2014) 958–965.
[11] Z. Xu, H. Hu, Projection models for intuitionistic fuzzy multiple attribute decision making, Int. J. Inf. Technol. Decis. Making 9 (2) (2010) 267–280.
[12] X. Zhang, Z. Xu, Extension of TOPSIS to multiple criteria decision making with Pythagorean fuzzy sets, Int. J. Intell. Syst. 29 (12) (2014) 1061–1078.
[13] G. Wei, M. Lu, Pythagorean fuzzy power aggregation operators in multiple attribute decision making, Int. J. Intell. Syst. 33 (1) (2018) 169–186.
[14] M. Lu, G. Wei, F.E. Alsaadi, T. Hayat, A. Alsaedi, Hesitant pythagorean fuzzy hamacher aggregation operators and their application to multiple attribute decision making, J. Intell. Fuzzy Syst. 33 (2) (2017) 1105–1117.
[15] M. Adabitabar Firozja, et al., A new similarity measure for Pythagorean fuzzy sets, Complex & Intell. Systems 6 (2020) 67–74, https://doi.org/10.1007/s40747-019-0114-3.
[16] Paul Augustine Ejegwa, Pythagorean fuzzy set and its application in career placements based on academic performance using max–min–max composition, Complex & Intell. Systems 5 (2019) 165–175, https://doi.org/10.1007/s40747-019-0091-6.
[17] K. Rahman, et al., Interval-valued Pythagorean fuzzy geometric aggregation operators and their application to group decision making problem, Cogent Mathematics 4 (1) (2017), 1338638, https://doi.org/10.1080/23311835.2017.1338638.
[18] T. Kumar, et al., On Accuracy Function and Distance Measures of Interval-Valued Pythagorean Fuzzy Sets with Application in Decision Making, Scientia Iranica, 2019, https://doi.org/10.24200/sci.2019.51579.2260.
[19] Harish Garg, A new improved score function of an interval-valued pythagorean fuzzy set based topsis method, Int. J. Uncertain. Quantification 7 (5) (2017) 463–474.
[20] Shu-Ping Wan, et al., A New Ranking Method for Pythagorean Fuzzy Numbers, 12th International Conference on Intelligent Systems and Knowledge Engineering, ISKE), 2017.
[21] Muhammad Akram, et al., Group decision-making based on pythagorean fuzzy TOPSIS method, Int. J. Intell. Syst. (2019) 1–21, https://doi.org/10.1002/int.22103.
[22] Mani Parimala, et al., Pythagorean fuzzy digraphs and its application in healthcare center, J. Math. 6 (2021), 5459654, https://doi.org/10.1155/2021/5459654.
[23] Harpreet Kaur, An algorithm to solve fuzzy job sequencing using pythagorean numbers, High Technol. Lett. 27 (2021) 7.
[24] Kumar Amit, et al., Mehar approach for solving dual-hesitant fuzzy transportation problem with restrictions, Sadhana 45 (2020) 77, https://doi.org/10.1007/s12046-020-01325-1.
[25] Ur Rehman Mahmood, A novel approach towards bipolar complex fuzzy sets and their applications in generalized similarity measures, Int. J. Intell. Syst. (2021) 1–33, 10.1002/int.22639.
[26] Kifayat Ullah, et al., On some distance measures of complex Pythagorean fuzzy sets and their applications in pattern recognition, Complex & Intelligent Systems 6 (2020) 15–27, https://doi.org/10.1007/s40747-019-0103-6.
[27] F. Göçer, G. Büyüközkan, A novel extension of Pythagorean fuzzy MULTIMOORA approach for new product development, Heliyon 9 (2023), e16726, https://doi.org/10.1016/j.heliyon.2023.e16726.
[28] R. Kumar, et al., A Pythagorean fuzzy approach to the transportation problem, Complex & Intell. Systems 5 (2019) 255–263, https://doi.org/10.1007/s40747-019-0108-1.
[29] R.M. Umamageswari, G. Uthra, A pythagorean fuzzy approach to solve transportation problem, Adalya J. 9 (1) (2020). ISSN No: 1301-2746.
[30] V. Jayapriya, R. Sophia Porchelvi, Pythagorean fuzzification and defuzzification functions, Malaya J. Matematik 9 (1) (2021) 286–290, https://doi.org/10.26637/MJM0901/0048.
[31] S. Divya Bharathi, G. Kanmani, Solving pythagorean transportation problem using arithmetic mean and harmonic mean, Int. J. Mech. Eng. 7 (2022) 4. ISSN: 0974-5823.
[32] S. Sathya Geetha, K. Selvakumari, A new method for solving pythagorean fuzzy transportation problem, PalArch's Journal of Archaeology of Egypt/Egyptology 17 (7) (2020).
[33] S. P Saranya, G. Charles Rabinson, An optimal algorithm for a pythagorean fuzzy transportation problem using decagonal numbers, Journal of Algebraic Statistics 13 (3) (2022) 1756–1762.
[34] Priyanka Nagar, et al., Optimization of fuzzy species pythagorean transportation problem under preserved uncertainties, Int. Journal of Mathematical, Engineering and Management Sciences 6 (6) (2021) 1629–1645, https://doi.org/10.33889/IJMEMS.2021.6.6.097.
[35] S. Krishna Prabha, et al., Geometric mean with pythagorean fuzzy transportation problem, Turkish Journal of Computer and Mathematics Education 12 (7) (2021) 1171–1176.

[36] Laxminarayan Sahoo, A new score function based Fermatean fuzzy transportation problem, Results in Control and Optimization 4 (2021), 100040, https://doi.org/10.1016/j.rico.2021.100040.
[37] K. Jeyalakshmi, et al., Pythagorean fuzzy transportation problem via Monalisha technique, Annals of R.S.C.B 25 (Issue 3) (2021) 2078–2086. ISSN:1583-6258.
[38] Harish Garg, Linguistic Pythagorean fuzzy sets and its applications in multiattribute decision-making process, Int. J. Intell. Syst. (2018) 1–31, https://doi.org/10.1002/int.21979.