



A new dynamic score function approach to optimize a special class of Pythagorean fuzzy transportation problem

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Abstract Endangered species are very important for our biodiversity and relocation is necessary to protect these species from extinction. In this paper, a pythagorean species fuzzy transportation problem is adopted to relocate these species. A new score function is proposed to defuzzify the pythagorean fuzzy numbers. In the literature, there are score functions in which the information about hesitation is missing but the proposed score function has the information about hesitation. Therefore, one can attain the accurate information about the pythagorean fuzzy numbers. Using proposed approach, these species are transferred at very minimum cost. To check the validity of proposed score function, comparison have been made with other existing score functions. Numerical illustrations are given to justify the proposed approach. Finally, a comparative study for transportation cost and allocations with the existing methods has been done to show the effectiveness of proposed score function.

Keywords Transportation problem · Fuzzy transportation problem · Pythagorean fuzzy numbers · Species transportation · Score function

Mathematics Subject Classification 90C70 · 90B06 · 90B50 · 90C05

1 Introduction

A variety of species living in forest area faces various challenges, such as forest fires and it has been studied in Doerr and Santín (2016); Rodrigues et al. (2020); Westerling (2016) that these forest fires will burn more areas in coming years. The reason behind these intense and frequent wildfires is change in climate and weather (Keeley and Syphard 2016) and global warming (D'Antonio and Vitousek 1992) is making the condition more worst. These wildfires affect the abundance, genetic diversity and distribution of species and considered as life threatening (Turner 2010; Griffiths and Brook 2014; Banks et al. 2013). Anthropogenic and natural factors both are responsible for harming animals (Karki 2002). Recently, Australian mega-fires destroy the ecological communities and habitats of threatened species. The effects on wild species of Australian forest have been discussed in Wintle et al. (2020) and studied that the impact of these wildfires on species will be long-lasting and it will take many years to again establish these fire-affected species in any other unburnt habitats. In fact, some of the unknown species become extinct because of these fires.

To protect these fire-affected species, relocation of these species to unburned areas is a challenging task. As, in this relocation, the risk of injury and death of these species is possible (Whelan et al. 2002). Species movement in optimized time with climate change has been discussed in McDonald-Madden et al. (2011). Olden et al. (2011) provided the strategies for managed relocation of species.

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Species relocation programmes in Australia are evaluated in a very interesting manner in Sheean et al. (2012). Relocation of these species from burnt areas to unburnt areas at minimum cost is the key concept of this study.

Transportation models offer a impressive scheme to fulfill this challenge. Linear programming problem has a special class of problem termed as transportation problem. Prof. F. L. Hitchcock (1941) (Hitchcock 1941) is the man who formulated transportation problem (TP) in early 1940s. TP plays a pivotal role in solving real-life problems. In the conventional model of TP (Hitchcock 1941), all the parameters are taken in precise form. But, in real world situations, like in any organization or in any industry, the values of these parameters (i.e., availability, requirements and cost of product) of the TP are not certain, imprecise and inconsistency in nature. These uncertainties in data is the reason behind the impreciseness in outcome or conclusion. To get rid of this type of uncertainty, Prof. Lotfi A. Zadeh (Zadeh 1965; Srivastava et al. 2018; Bisht et al. 2018; Srivastava and Bisht 2019) suggested the concept of uncertainty in the mid of 1960s. In 1970, two mathematicians, (Bellman and Zadeh 1970) extend the concept of fuzzy set to TP and suggested the term fuzzy transportation problems (FTPs) to the world. Optimization of fuzzy transportation problems become very popular among researchers because of their several applications in our day-today's life. Various types of techniques have been developed by researchers to solve fuzzy transportation problems (Srivastava et al. 2020; Chhibber et al. 2021). Later, (Chanas et al. 1984) and (Chanas and Kuchta 1996) worked out on fuzzy transportation problems in 1984. TP in fuzzy environments like integer fuzzy (Tada and Ishii 1996), type-2 fuzzy (Kundu et al. 2014; Singh and Yadav 2016; Gupta and Kumari 2017), interval integer fuzzy (Akilbasha et al. 2018), interval-valued intuitionistic fuzzy (Bharati and Singh 2018), multi-objective (Hashmi et al. 2019; Li and Lai 2000; Pramy 2017) and interval-valued fuzzy fractional (Arora 2018) are adopted to optimized TP in fuzzy situations. Liu and Lao (2004) used extension principle for finding the travel cost of TP. Two stage technique is adopted for the solution of given problem in Gani and Razak (2006). A new idea is developed to solve FTPs in Kaur and Kumar (2011); Mathur and Srivastava (2020). Transportation problems having all the parameter in interval form is optimized using a non-fuzzy method by Pandian and Natarajan (2010). Solid TP is optimized in Liu et al. (2014). Zero point and zero suffix method are suggested for fully fuzzy transportation problems solution (Ngastiti and Surarso 2018). A technique named as Modified best candidate is used to find solution for fuzzy transportation problem (Dinagar and Keerthivasan 2018). Incenter of triangle is used to develop a ranking function in Srivastava and Bisht (2018). Literature survey of existing

techniques related to fuzzy transportation problems has been done in Mathur et al. (2018). Optimization of different type of TP is given in Nagar et al. (2019). Trapezoidal and hexagonal fuzzy numbers are employed for optimization in Mathur et al. (2016); Mathur and Srivastava (2019); Bisht and Srivastava (2019). To optimize fuzzy transportation cost, a new conversion approach is suggested in Bisht and Srivastava (2017). Type-1 and Type-2 fuzzy TP are solved in Chhibber et al. (2019). Pythagorean fuzzy numbers are used in Kumar et al. (2019); Umamageswari and Uthra (2020). Transportation problem in fermatean fuzzy environment is solved in Sahoo (2021). An integrated mathematical model for a green solid transportation system has been introduced in Das et al. (2020). Three new improved score functions are proposed for ranking of fermatean fuzzy sets (Sahoo 2021). Multi-stage multi-objective fixed-charge solid transportation problem via a green supply chain has been studied in Midya et al. (2021). Fixed-charge solid transportation problem is adopted in multi-objective environment and intuitionistic fuzzy numbers are used as parametric values in Ghosh et al. (2021). A new defuzzification technique which is based on statistical beta distribution has been used to solve assignment problem with linguistic costs in Sahoo and Ghosh (2017). Matrix games with linguistic payoffs are solved by Sahoo (2019) and different defuzzification techniques are used to solve fuzzy matrix games (Sahoo 2015). Species transportation is very essential for proper functioning of our ecosystems. Domestic animals, endangered animals etc. are some common species which are transported from one place to another just to protect these species.

Table 1, shows some significant work in various fuzzy environment. After reviewing the existing work, authors observed that, only few work has been done on pythagorean fuzzy transportation problems. This motivate authors to developed a unique technique based on score function which is more effective as compared to the existing techniques.

The main contribution of the paper is as follows:

1. In this article, a new idea is proposed to get the optimized result of the given TP in which all the parameters are Pythagorean fuzzy numbers.
2. In the proposed work, a unique score function is developed to defuzzify Pythagorean fuzzy numbers.
3. After defuzzifying, minimum-demand supply technique is adopted to find the initial basic feasible solution (IBFS) of the obtained defuzzified TP.
4. Conventional MODI method is applied to find the optimal result of the obtained IBFS.

Rest of the work is arranged in the following manner: Sect. 2, defines Pythagorean fuzzy set (PFS) and properties

Table 1 Significant work by different authors using various fuzzy environment

| Author and references | Year | Significant work |
|--------------------------|------|---|
| (Kaur and Kumar 2011) | 2011 | A new method based on classical method is proposed and generalized fuzzy numbers are used to find IBFS |
| (Liu and Lao 2004) | 2014 | Type-2 fuzzy environment is considered and three types of defuzzication methods are developed |
| (Kundu et al. 2014) | 2014 | Critical-value based reduction technique to defuzzify type-2 fuzzy environment into type-1 fuzzy environment |
| (Akilbasha et al. 2018) | 2018 | Mid-width method is used to obtain two different TP by a single fuzzy transportation problem and obtained optimal cost in Traingular fuzzy numbers |
| (Bharati and Singh 2018) | 2018 | Interval-valued intuitionistic fuzzy (IVIF) sets are used and author shows that cost of transportation using IVIF sets is lesser than fuzzy and intuitionistic fuzzy sets |
| (Kumar et al. 2019) | 2019 | TP under Pythagorean fuzzy environment are solved using a new algorithm |

of the PFS while in Sect. 3, existing score functions and their limitations are defined. In Sect. 4, proposed score function and comparison with existing score function are shown and in Sect. 5, the whole methodology of the work has been represented. Section 6 provides the illustrations to show the feasibility of the proposed score function and comparative study with the methods present in literature has been done in Sect. 7. Last section provides the conclusion of the work.

2 Pythagorean fuzzy set

It is observed in some cases that after summing up the membership degree and non-membership degree, the sum is greater than 1. To deal with this condition, Yager (Yager 2014; Yager and Abbasov 2013; Yager 2013) recently discovered Pythagorean fuzzy set, which defines that on summing up the square of membership degree and the square of non-membership degree the resultant is less than or equal to 1. Let Λ be a universal set and a pythagorean fuzzy set δ in Λ is defined as

$$\delta = \{ \langle z, \psi_\delta(z), \chi_\delta(z) \rangle | z \in \Lambda \}$$

where $\psi_\delta(z) : \Lambda \rightarrow [0, 1]$ represents the degree of membership and $\chi_\delta(z) : \Lambda \rightarrow [0, 1]$ represents the degree of non-membership of $z \in \Lambda$ to the set δ , respectively, also for every $z \in \Lambda$ it satisfies the condition

$$(\psi_\delta(z))^2 + (\chi_\delta(z))^2 \leq 1$$

The degree of hesitation is find out by the following equation

$$\pi_\delta(z) = \sqrt{1 - (\psi_\delta(z))^2 - (\chi_\delta(z))^2}$$

2.1 Properties of Pythagorean fuzzy numbers

Let $\tau = (\psi_1, \chi_1)$ and $\sigma = (\psi_2, \chi_2)$ be two pythagorean fuzzy numbers (PFNs). Then following arithmetic operations are defined as below:

- (i) $\tau \oplus \sigma = (\sqrt{\psi_1^2 + \psi_2^2 - \psi_1 \cdot \psi_2}, \chi_1 \cdot \chi_2)$;
- (ii) $\tau \otimes \sigma = (\psi_1 \cdot \psi_2, \sqrt{\chi_1^2 + \chi_2^2 - \chi_1 \cdot \chi_2})$;
- (iii) $\beta \cdot \tau = (\sqrt{1 - (1 - \psi_1^2)^\beta}, \chi_1^\beta)$, where $\beta > 0$;
- (iv) $\tau \cup \sigma = (\max(\psi_1, \psi_2), \min(\chi_1, \chi_2))$;
- (v) $\tau \cap \sigma = (\min(\psi_1, \psi_2), \max(\chi_1, \chi_2))$.

3 Score functions present in literature and their limitations

Let $\tau = \langle \psi, \chi, \pi \rangle$ be a pythagorean fuzzy number (PFN). Here ψ, χ, π represent the support, opposition and hesitation respectively.

A score function proposed by Zhang and Xu (2014) is given by the following expression

$$S_Z(\tau) = ((\psi)^2 - (\chi)^2), S_Z(\tau) \in [-1, 1] \tag{1}$$

For two pythagorean fuzzy numbers, $\tau = (0.4, 0.4)$ and $\sigma = (0.5, 0.5)$, the score function defined in (1) gives

$$S_Z(\tau) = 0 \text{ and } S_Z(\sigma) = 0$$

From the above expression it can be easily seen that decision maker cannot distinguish the difference between two PFNs. Hence, this score function is not suitable for finding the best alternative between two PFNs.

To overcome the deficiency of this score function (Peng and Yang 2015) defined an accuracy function as

$$H_P(\tau) = ((\psi)^2 + (\chi)^2), H_P(\tau) \in [0, 1] \tag{2}$$

After that (Ma and Xu 2016) proposed the modified score function and accuracy function as follows

$$S_{ma}(\tau) = \begin{cases} \sqrt{(\psi)^2 - (\chi)^2} \text{ iff } \psi \geq \chi \\ -\sqrt{(\chi)^2 - (\psi)^2} \text{ iff } \psi \leq \chi \end{cases}, S_{ma}(\tau) \in [-1, 1] \tag{3}$$

$$H_{ma}(\tau) = \sqrt{(\psi)^2 + (\chi)^2}, H_{ma}(\tau) \in [0, 1] \tag{4}$$

The score function defined in (3) gives the same result as the case above. Also, it can be seen that the score function $S_Z(\tau)$ and $S_{ma}(\tau)$, and accuracy function $H_P(\tau)$ and $H_{ma}(\tau)$ did not take the information about hesitation, which clearly implies that the information of PFN will not attain accurately. (Table 2)

4 New score function for pythagorean fuzzy numbers

The score function is a key concept in Pythagorean fuzzy decision-making problems. It is defined in such a way that bigger the value of it, the more befittingly the relevant alternative will be able to meet the expectation of experts.

A dynamic score function consists of three terms namely belongingness degree, non- belongingness degree and degree of hesitation. For any PFN $\tau = (\psi, \chi)$ the definition of this PFN can be easily understood by a voting model (Alcantud and Laruelle 2014). Suppose ψ represents the support for any candidate, χ shows opposition and π shows hesitation in choosing candidate. Consider that the hesitate person may be influenced by supporters or opponents and thus change his decision to support and oppose. The proportion of the hesitate part is not certain as it can support as well as oppose. If the number of supporters are more then hesitate part is in favor of candidate and if opponents are more then hesitate part can go in opposition party. Seeing the importance of hesitate part, the new score function is defines as:

$$S_{Prop.} = \frac{2\psi^2 - \chi^2}{2 - \psi^2 - \chi^2} - \frac{1}{2} \tag{5}$$

Definition 1 For any two PFNs $\tau = (\psi_1, \chi_1)$ and $\sigma = (\psi_2, \chi_2)$,

- (i) If $S_{Prop.}(\tau) > S_{Prop.}(\sigma)$, then $\tau > \sigma$
- (ii) If $S_{Prop.}(\tau) < S_{Prop.}(\sigma)$, then $\tau < \sigma$
- (iii) If $S_{Prop.}(\tau) = S_{Prop.}(\sigma)$, then
 - (a) If $\pi_\tau > \pi_\sigma$, then $\tau > \sigma$
 - (b) If $\pi_\tau = \pi_\sigma$, then $\tau = \sigma$

Definition 2 For any two PFNs $\tau = (\psi_1, \chi_1)$ and $\sigma = (\psi_2, \chi_2)$,

- (i) $0 \leq S_{Prop.} \leq 1$;
- (ii) $S_{Prop.} = 1$ iff $\tau = (0, 1)$; $S_{Prop.} = 0$ iff $\tau = (1, 0)$

5 Methodology

This section provides the procedure of finding optimal result in transporting species from their habitats to other habitats. In this study, a Pythagorean fuzzy environment is taken and using proposed score function, Pythagorean fuzzy numbers are converted into crisp numbers. Then, minimum demand-supply method is adopted to find the IBFS of defuzzified transportation problem. Finally, optimal solution of IBFS is obtained using MODI method.

Following are steps that are to be followed to obtain minimum cost of transportation.

STEP A. Firstly, convert the given problem into tabular form.

STEP B. Pythagorean fuzzy numbers are converted into crisp numbers using the score function which is proposed in Sect. 4.

STEP C. After defuzzification, obtained problem is examined to get the balanced one.

Table 2 Comparison table of score function

| Examples | Score value | Ranking |
|--|--|---|
| $\tau = (0.5, 0.5), \sigma = (0.6, 0.6)$ | $S_{prop.}(\tau) = 0.25, S_{prop.}(\sigma) = 0.4218$ $S_{ma}(\tau) = 0, S_{ma}(\sigma) = 0$ $S_Z(\tau) = 0, S_Z(\sigma) = 0$ | $\tau < \sigma$ $\tau = \sigma$ $\tau = \sigma$ |
| $\tau = (0.7, \sqrt{0.4}), \sigma = (0.5, 0.4)$ | $S_{prop.}(\tau) = 0.6883, S_{prop.}(\sigma) = 0.2541$ $S_{ma}(\tau) = 0.3, S_{ma}(\sigma) = 0.3$ $S_Z(\tau) = 0.09, S_Z(\sigma) = 0.09$ | $\tau > \sigma$ $\tau = \sigma$ $\tau = \sigma$ |
| $\tau = (0.7, \sqrt{0.38}), \sigma = (0.6, 0.5)$ | $S_{prop.}(\tau) = 0.6826, S_{prop.}(\sigma) = 0.4146$ $S_{ma}(\tau) = 0.3317, S_{ma}(\sigma) = 0.3317$ $S_Z(\tau) = 0.11, S_Z(\sigma) = 0.11$ | $\tau > \sigma$ $\tau = \sigma$ $\tau = \sigma$ |

- If total supply is equal to total demand, then go to Step D.
- If total supply is greater than total demand, then add a dummy zero column to balanced the TP and then go to Step D.
- If total demand is greater than total supply, then add a dummy zero row to balanced the TP and then go to Step D.

STEP D. After balancing the TP, initial basic feasible solution (IBFS) is found out using the following steps:

- Find the minimum of supply and demand and check for row or column in which minimum demand and supply occur then allocate the least cost in that row or column.

Determination of $b_{ij} = \min(a_i, r_j)$

- If $\min(a_i, r_j) = a_i$ then locate $b_{ij} = a_i$ in (i, j) cell of balanced TP of order $(p \times q)$ and remove that row to get reduced TP of order $(p - 1) \times q$. Now, write $a_i - r_j$ in place of a_i in reduced TP.
- If $\min(a_i, r_j) = r_j$ then locate $b_{ij} = a_i$ in (i, j) cell of balanced TP of order $(p - 1 \times q)$ and remove that row to get reduced TP of order $(p - 1) \times (q - 1)$. Now, write $a_i - r_j$ in place of a_i in reduced TP.
- If $a_i = r_j$, then allocate that cell in which cost is minimum.
- If there are equal transporting cost, then allocate that cell in which $\min(a_i, r_j)$.
- Repeat Step D, until the balanced $(p \times q)$ matrix decrease to order 1.

In this way, IBFS of the given TP is obtained.

STEP E. MODI method is adopted to check the optimality of the obtained IBFS. (Fig. 1)

6 Illustrative example

Example 1 Consider a Pythagorean fuzzy transportation problem described in Kumar et al. (2019) in Table 3. In Table 3, cost of transporting endangered species from one ecosystem to another is given in pythagorean fuzzy numbers and demand and supply of species is given in a certain form.

Using the proposed score function, the defuzzified pythagorean fuzzy transportation is given by the following Table 4.

Here $\sum a_i = 26 + 24 + 30 = 80$ and $\sum b_i = 17 + 23 + 28 + 12 = 80$. This shows that the above transportation problem is balanced.

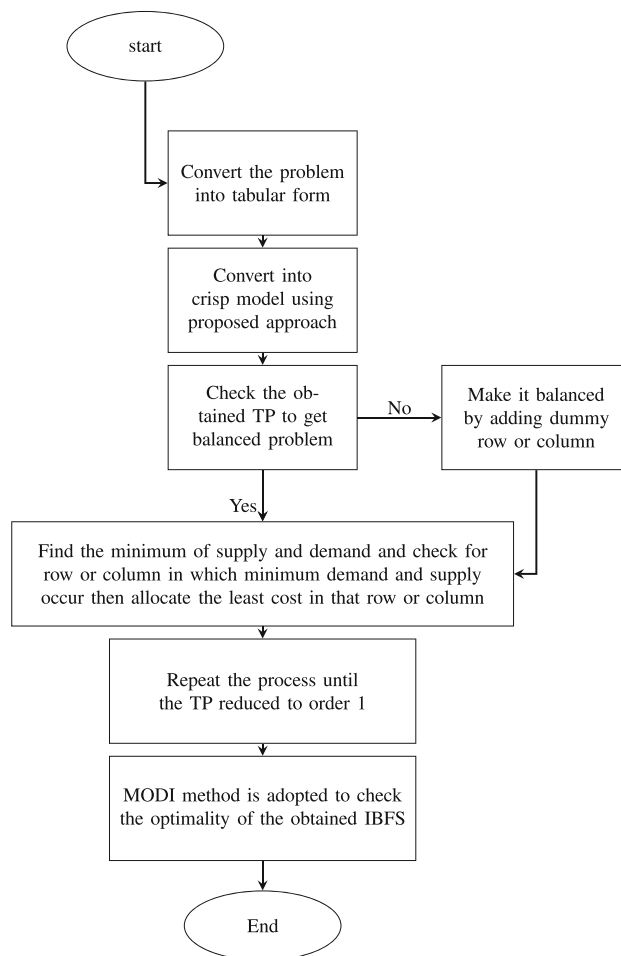


Fig. 1 Flowchart of proposed approach

Table 3 Input data for example 1

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|------------|------------|------------|------------|--------|
| Q_1 | (0.4, 0.7) | (0.5, 0.4) | (0.8, 0.3) | (0.6, 0.3) | 26 |
| Q_2 | (0.4, 0.2) | (0.7, 0.3) | (0.4, 0.8) | (0.7, 0.3) | 24 |
| Q_3 | (0.7, 0.1) | (0.8, 0.1) | (0.6, 0.4) | (0.9, 0.1) | 30 |
| Demand | 17 | 23 | 28 | 12 | |

Table 4 Defuzzified pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-------|-------|-------|-------|--------|
| Q_1 | 0.06 | 0.11 | 0.44 | 0.19 | 26 |
| Q_2 | 0.07 | 0.29 | 0.06 | 0.29 | 24 |
| Q_3 | 0.29 | 0.43 | 0.18 | 0.65 | 30 |
| Demand | 17 | 23 | 28 | 12 | |

Now to find the initial basic feasible solution (IBFS) of above linear programming problem, minimum demand-supply technique is applied below:

Table 5 shows the first allotment cell at $(Q_1, P_4) = x_{14} = 12$, using minimum demand-supply method.

Table 6 shows the second allotment cell at $(Q_1, P_1) = x_{11} = 14$, using minimum demand-supply method.

Table 7 shows the third allotment cell at $(Q_2, P_1) = x_{21} = 3$, using minimum demand-supply method.

Table 8 shows the fourth allotment cell at $(Q_2, P_3) = x_{23} = 21$, using minimum demand-supply method.

Table 9 shows the fifth allotment cell at $(Q_3, P_3) = x_{33} = 7$, using minimum demand-supply method.

Table 10 shows the final allotment cell at $(Q_3, P_2) = x_{32} = 23$, using minimum demand-supply method and obtained initial basic feasible solution is:

$(Q_1, P_1) = x_{11} = 14$, $(Q_1, P_4) = x_{14} = 12$,
 $(Q_2, P_1) = x_{21} = 3$, $(Q_2, P_3) = x_{23} = 21$,
 $(Q_3, P_2) = x_{32} = 23$, $(Q_3, P_3) = x_{33} = 7$. Transportation cost = 15.74

To test the optimality, modified distribution method is used in the IBFS. The basic variables are obtained as

$(Q_1, P_2) = x_{12} = 21$, $(Q_1, P_4) = x_{14} = 5$,
 $(Q_2, P_1) = x_{21} = 17$, $(Q_2, P_4) = x_{24} = 7$,
 $(Q_3, P_2) = x_{32} = 2$, $(Q_3, P_3) = x_{33} = 28$.

Hence, the minimum transportation cost = 12.38

Example 2 Consider a Pythagorean fuzzy transportation problem described (Kumar et al. 2019) in Table 11. In this Table, cost of transporting endangered species from one ecosystem to another is given in crisp form and demand and supply of species is given in a pythagorean fuzzy numbers.

Using the proposed score function, the defuzzified pythagorean fuzzy transportation is given by the following Table 12.

Now to find the initial basic feasible solution (IBFS) of above transportation problem, minimum demand-supply technique is applied and obtained initial basic feasible solution is:

$(I_1, G_1) = x_{11} = 0.0595$, $(I_1, G_4) = x_{14} = 0.1912$,
 $(I_2, G_2) = x_{22} = 0.2861$, $(I_2, G_3) = x_{23} = 0.4308$,
 Transportation cost = 0.060128

Table 5 Allotment of first allocation in pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-------|-------|-------|-----------|--------|
| Q_1 | 0.06 | 0.11 | 0.44 | 0.19 (12) | 14 |
| Q_2 | 0.07 | 0.29 | 0.06 | 0.29 | 24 |
| Q_3 | 0.29 | 0.43 | 0.18 | 0.65 | 30 |
| Demand | 17 | 23 | 28 | – | |

Table 6 Allotment of second allocation in pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-----------|-------|-------|-----------|--------|
| Q_1 | 0.06 (14) | 0.11 | 0.44 | 0.19 (12) | – |
| Q_2 | 0.07 | 0.29 | 0.06 | 0.29 | 24 |
| Q_3 | 0.29 | 0.43 | 0.18 | 0.65 | 30 |
| Demand | 3 | 23 | 28 | – | |

Table 7 Allotment of third allocation in pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-----------|-------|-------|-----------|--------|
| Q_1 | 0.06 (14) | 0.11 | 0.44 | 0.19 (12) | – |
| Q_2 | 0.07(3) | 0.29 | 0.06 | 0.29 | 21 |
| Q_3 | 0.29 | 0.43 | 0.18 | 0.65 | 30 |
| Demand | – | 23 | 28 | – | |

Table 8 Allotment of fourth allocation in pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-----------|-------|-----------|-----------|--------|
| Q_1 | 0.06 (14) | 0.11 | 0.44 | 0.19 (12) | – |
| Q_2 | 0.07 (3) | 0.29 | 0.06 (21) | 0.29 | – |
| Q_3 | 0.29 | 0.43 | 0.18 | 0.65 | 30 |
| Demand | – | 23 | 7 | – | |

Table 9 Allotment of fifth allocation in pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-----------|-------|-----------|-----------|--------|
| Q_1 | 0.06 (14) | 0.11 | 0.44 | 0.19 (12) | – |
| Q_2 | 0.07 (3) | 0.29 | 0.06 (21) | 0.29 | – |
| Q_3 | 0.29 | 0.43 | 0.18 (7) | 0.65 | 23 |
| Demand | – | 23 | – | – | |

To test the optimality, modified distribution method is used in the IBFS. The basic variables are obtained as

$(I_1, G_1) = x_{11} = 0.0595$, $(I_1, G_2) = x_{12} = 0.0358$,
 $(I_1, G_4) = x_{14} = 0.1912$, $(I_2, G_3) = x_{23} = 0.4308$,
 $(I_3, G_2) = x_{32} = 0.2503$.

Hence, the minimum transportation cost = 0.04780

Table 10 Allotment of final allocation in pythagorean fuzzy transportation problem

| | P_1 | P_2 | P_3 | P_4 | Supply |
|--------|-----------|-----------|-----------|-----------|--------|
| Q_1 | 0.06 (14) | 0.11 | 0.44 | 0.19 (12) | – |
| Q_2 | 0.07 (3) | 0.29 | 0.06 (21) | 0.29 | – |
| Q_3 | 0.29 | 0.43 (23) | 0.18 (7) | 0.65 | – |
| Demand | – | – | – | – | |

Table 11 Input data for example 2

| | G_1 | G_2 | G_3 | G_4 | Supply |
|--------|-----------|-----------|-----------|---------------|-----------|
| I_1 | 0.0355 | 0.0545 | 0.0775 | 0.0635 | (0.7,0.1) |
| I_2 | 0.056 | 0.07 | 0.026 | 0.07 | (0.8,0.1) |
| I_3 | 0.074 | 0.0815 | 0.06 | 0.09 | (0.9,0.1) |
| Demand | (0.4,0.7) | (0.7,0.3) | (0.8,0.1) | (0.60832,0.4) | |

Table 12 Defuzzified pythagorean fuzzy transportation problem

| | G_1 | G_2 | G_3 | G_4 | Supply |
|--------|--------|--------|--------|--------|--------|
| I_1 | 0.0355 | 0.0545 | 0.0775 | 0.0635 | 0.2865 |
| I_2 | 0.056 | 0.07 | 0.026 | 0.07 | 0.4308 |
| I_3 | 0.074 | 0.0815 | 0.06 | 0.09 | 0.6503 |
| Demand | 0.0595 | 0.2861 | 0.4308 | 0.1912 | |

7 Comparative study

In this section, comparative study has been done for cost of transportation, for place of allocations and with classical method respectively. Transportation cost, place of allocation and comparison with classical methods of IBFS for example 1 and example 2, attained by proposed technique are compared with (Kumar et al. 2019) and (Umamageswari and Uthra 2020).

In Table 13, it can be seen that using the proposed approach, obtained transportation cost is very less as compared to other existing approaches (Kumar et al. 2019) and (Umamageswari and Uthra 2020).

In Table 14, it can be seen that using the proposed approach, obtained transportation cost is less as compared to other existing approaches (Kumar et al. 2019) and (Umamageswari and Uthra 2020).

In Table 15, it can be seen that using the proposed method, Q_1 maps P_2 and P_4 in which P_2 has minimum transportation cost in the first row, Q_2 maps P_1 and P_3 in which P_3 has minimum transportation cost in the second row and Q_3 maps P_2 and P_3 in which P_3 has minimum transportation cost in the third row. This shows that, most

Table 13 Table of comparison for cost of transportation for example 1

| | Transportation cost |
|-------------------------------|---------------------|
| (Kumar et al. 2019) | 41.45 |
| (Umamageswari and Uthra 2020) | 27.48 |
| Proposed approach | 12.38 |

Table 14 Table of comparison for cost of transportation for example 2

| | Transportation cost |
|-------------------------------|---------------------|
| (Kumar et al. 2019) | 0.132978 |
| (Umamageswari and Uthra 2020) | 0.050195 |
| Proposed approach | 0.047685 |

of the time, the proposed method allocates those cells which have minimum transportation cost for supplying one unit which results in overall minimizing the transportation cost. On the other hand, existing methods allocates those cells which have high transportation cost.

In Table 16, it can be seen that using the proposed method, I_1 maps G_1 , G_2 and G_4 in which G_1 has minimum transportation cost in the first row, I_2 maps G_3 and it has minimum transportation cost in the second row and I_3 maps G_2 in which G_3 has minimum transportation cost in the third row. This shows that, most of the time, the proposed method allocates those cells which have minimum transportation cost for supplying one unit which results in overall minimizing the transportation cost. On the other hand, existing methods allocates those cells which have high transportation cost.

In Table 17, initial basic feasible solution of Table 4 (Defuzzified pythagorean fuzzy transportation problem) is found out using classical methods and minimum demand-supply method. It can be seen from the table that minimum demand-supply methods works better than North-West Corner and Least Cost Method.

In Table 18, initial basic feasible solution of Table 12 (Defuzzified pythagorean fuzzy transportation problem) is found out using classical methods and minimum demand-supply method.

8 Conclusions and future work

Shifting of rare species or new discovered species at the time of forest fire is very important for the protection of our biodiversity. This paper optimizes a different kind of TP known as Pythagorean species fuzzy TP. A unique score

Table 15 Table of comparison for allocation for example 1

| | P_1 | | P_2 | | P_3 | | P_4 | | |
|-------|---------------------|-------------------------------|----------------|---------------------|-------------------------------|----------------|---------------------|-------------------------------|----------------|
| | (Kumar et al. 2019) | (Umamageswari and Uthra 2020) | Prop. approach | (Kumar et al. 2019) | (Umamageswari and Uthra 2020) | Prop. approach | (Kumar et al. 2019) | (Umamageswari and Uthra 2020) | Prop. approach |
| Q_1 | ✓ | × | ✓ | ✓ | × | × | × | ✓ | ✓ |
| Q_2 | × | ✓ | ✓ | × | × | × | × | ✓ | × |
| Q_3 | × | × | × | ✓ | ✓ | ✓ | ✓ | × | × |

Table 16 Table of comparison for allocation for example 2

| | G_1 | | G_2 | | G_3 | | G_4 | | |
|-------|---------------------|-------------------------------|----------------|---------------------|-------------------------------|----------------|---------------------|-------------------------------|----------------|
| | (Kumar et al. 2019) | (Umamageswari and Uthra 2020) | Prop. approach | (Kumar et al. 2019) | (Umamageswari and Uthra 2020) | Prop. approach | (Kumar et al. 2019) | (Umamageswari and Uthra 2020) | Prop. approach |
| I_1 | ✓ | ✓ | ✓ | ✓ | × | × | × | × | ✓ |
| I_2 | × | × | × | × | ✓ | ✓ | × | × | × |
| I_3 | × | ✓ | × | ✓ | × | × | ✓ | ✓ | × |

Table 17 Table of comparison for IBFS with classical methods for example 1

| Scheme | IBFS | Optimal solution |
|------------------------------|-------|------------------|
| North-West corner | 17.71 | 12.38 |
| Least cost method | 17.99 | 12.38 |
| Vogel's approximation method | 12.65 | 12.38 |
| Minimum demand-supply method | 15.74 | 12.38 |

Table 18 Table of comparison for IBFS with classical methods for example 2

| Scheme | IBFS | Optimal solution |
|------------------------------|------|------------------|
| North-West corner | 0.05 | 0.04 |
| Least cost method | 0.06 | 0.04 |
| Vogel's approximation method | 0.05 | 0.04 |
| Minimum demand-supply method | 0.06 | 0.04 |

function is proposed to defuzzify special types of fuzzy numbers, termed as Pythagorean fuzzy numbers. It can be clearly seen from the comparative study that developed score function is more efficient than the other existing methods. Cost of transportation found out using suggested score function is very less, compared to other techniques. The proposed score function is easy to compute and applicable in real world problems. For future research work, the present study can be applied to solve fuzzy transportation problem in any pandemic situation to transfer a variety of species.

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Conflict of interest On behalf of all the authors, the corresponding author declares that there is no conflict of interest.

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