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An alternate method for finding more for less solution to fuzzy transportation problem with mixed constraints

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Abstract

In this paper, we present a different process for the optimal solution to mixed constraints transportation problem with imprecise coefficients without changing to its crisp equivalent form which is very distinct from other existing methods. Here, all the variables are considered to be triangular fuzzy numbers. Utilizing a parametric form of triangular fuzzy numbers such as left fuzziness index, right fuzziness index, modal value and by using proposed algorithm, we obtained the initial basic fuzzy feasible solution to the problem without changing to its crisp equivalent form. To obtain the solution, we use fuzzy ranking dependent on left and right spreads at some S-level of fuzzy numbers and fuzzy arithmetic dependent on both location index function and fuzziness index function. We further discuss the more for less solution by obtaining shadow prices to the problem. The more for less situation occurs when we raise the supplies, and demand quantities may cause to reduce the optimal transportation cost. The more for less paradox is very useful to a manager in dynamic, for example expanding an item house loading level or plant age breaking point and publicizing attempts to build request at explicit markets. A numerical example is solved to show the adequacy of the proposed algorithm.

Keywords Fuzzy transportation problem · Mixed constraints · More for less paradox · Triangular fuzzy numbers · Fuzzy arithmetic operation

1 Introduction

Transportation problem is the most successful utilization of linear programming problems to taking care of business issues that have been in the physical dispersion of items. In this problem, m sources and n destinations are given, and the products have to be taken from these sources to destinations such that minimize the transporting cost. The number of stocks transported is directly proportional to the transportation cost from sources to destination. Mixed constraints transportation problem is a problem in which the sources and destination constraints consists equality constraints as well as less than or equal to and greater than or equal to constraints. But in practical issues, there are situations such that cost coefficients, availability and demand quantities quite possibly uncertain due to some uncontrollable factors. Therefore, regular mathematical techniques cannot be used to solve the transportation problem involving imprecise information.

To deal with, Zadeh (1965) initiated the notion of fuzzy sets. Zadeh applied the fuzzy set theory effectively in different fields to manage unsure information in making decision. After the foremost work performed by Bellman and Zadeh (1970), the applications of this theory grows rapidly in the optimization field. A wide range of techniques have been created by several researchers such as Vidhya and Ganesan (2019), Juman and Nawarthne (2019), Kumar and Jha (2019) and Christi (2017) for the solution of transportation problem. Joshi et al. (2017) used improved VAM method to determine the feasible solution for mixed constraints fuzzy transportation problem. Mondal et al. (2012) solved mixed constraint problem by

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modified VAM method, and also by using simplex algorithm, they developed a computer program for solving such problems. Kumar and Kumar (2018) introduced an additional row and column for transforming mixed constraints transshipment problem into a corresponding classical transportation problem and solved by zero suffix method. Akilbasha et al. (2017) solved fully rough integer interval transportation problem by applying rough slice sum method.

Khurana and Arora (2011) proposed a simple process for finding the solution of both types of balanced and unbalanced linear transshipment mixed constraint problem. The more for less situation in a transportation problem exists when it is conceivable to transport increasingly add up to merchandise for less (or equivalent) absolute expense while delivering a similar sum or more from every starting point to every goal and keeping all the delivery costs positive. The more for less analysis is helpful to an administrator, for example, expanding stockroom or plant limits and which make ought to be looked for in decisions such as developing warehouse or plant capacities and which make should be sought. The occurrence of more for less in transportation problem is a regular event and observed in nature. Many researchers proposed various methods to find the more for less situation in transportation problem. Pandian and Natarajan (2010) determined optimal more for less solution to the problem by using different algorithm dependent on fuzzy zero point method. Adlakha (2011), Adlakha and Kowalski (1998), and Adlakha et al. (2006) developed a sufficient solution to more for less circumstances in the problem by just finding the absolute points. Moreover, we noticed that there are numerous process to solve transportation problem with mixed constraints such as ranking function (Hussain and Kumar 2013), genetic algorithm (Das et al. 2016), and improved VAM (Muthuperumal et al. 2018). In this paper, we develop a new process to obtain the initial fuzzy feasible solution to a fuzzy transportation problem with mixed constraints without changing to its crisp form and then we discuss the more for less circumstance. It is noted that the proposed algorithm is very simple and provides the fuzzy optimal solution directly. The organization of a paper is as follows: In Sect. 2, we define the basic concepts of triangular fuzzy number, rank and their arithmetic operators. Section 3 gives the formulation of fuzzy transportation with mixed constraints. In Sect. 4, we suggested a new algorithm for the solution of fuzzy transportation problem with mixed constraints, and in Sect. 5, a numerical example is solved to show the efficiency of the proposed method.

2 Preliminaries

Definition 2.1. A fuzzy set $\tilde{A}$ defined on the set of real numbers R is said to be a fuzzy number if its membership function $\tilde{A}: R \to [0,1]$ has the following characteristics:

(i) $\tilde{A}$ is convex
(i.e.,)

$$\tilde{A}(\lambda x_1 + (1-\lambda)x_2) \geq \min\{\tilde{A}(x_1), \tilde{A}(x_2)\},\quad \lambda \in [0,1],\ \forall x_1, x_2 \in R \tag{1}$$

(ii) $\tilde{A}$ is normal, i.e., there exists an x such that $\tilde{A}(x) = 1$

(iii) $\tilde{A}$ is piece-wise continuous.

Definition 2.2. A fuzzy number $\tilde{A}$ is said to be a triangular fuzzy number if its membership function $\tilde{A}: R \to [0,1]$ has the following characteristics:

$$\tilde{A}(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1} & \text{if } a_1 \leq x \leq a_2 \\ \dfrac{a_3-x}{a_3-a_2} & \text{if } a_2 \leq x \leq a_3 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Definition 2.3. A triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3) \in F(R)$ can also be represented with an ordered pair of functions through S-cut approach $[\underline{a}(S), \overline{a}(S)] = [(a_2-a_1)S + a_1, a_3 - (a_3-a_2)S]$ for $0 \leq S \leq 1$ which satisfies the following conditions:

(i) $\underline{a}(S)$ is a bounded monotonic increasing left continuous function.
(ii) $\overline{a}(S)$ is a bounded monotonic decreasing left continuous function.
(iii) $\underline{a}(S) \leq \overline{a}(S)$, where $0 \leq S \leq 1$.

The S-cut form is known as parametric form of fuzzy number. Moreover, the triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3)$ can also be denoted by parametric form $\tilde{A} = (a_0, a_*, a^*)$ where $a_* = (a_0 - \underline{a})$, $a^* = (\overline{a} - a_0)$ are said to be left fuzziness index function and the right fuzziness index function, respectively. The number $a_0 = \left(\frac{\underline{a}(1)+\overline{a}(1)}{2}\right)$ is called a location index number of $\tilde{A}$.

2.1 Ranking of triangular fuzzy numbers

For an arbitrary triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3) = (a_0, a_*, a^*)$ with parametric form $\tilde{a} = (\underline{a}(S), \overline{a}(S))$, we define the magnitude of the triangular fuzzy number by

$$\begin{aligned}\text{Mag}(\tilde{A}) &= \frac{1}{2}\left[\int_0^1 (\underline{a} + \ \overline{a} + a_0) f(S)\, \mathrm{d}S\right] \\ &= \frac{1}{2}\left[\int_0^1 (a* + 4a_0 - a_*) f(S)\, \mathrm{d}S\right]\end{aligned} \tag{3}$$

Here, the function *f*(*S*) is a nonnegative and increasing on [0, 1] with $f(0) = 0, f(1) = 1$ and $\int_0^1 f(S)\, \mathrm{d}S = \frac{1}{2}$.

It can be considered as a weighting function according to the situation the function *f*(*S*) can be assigned by the decision maker. Here, for convenience, *f*(*S*) = *S* has been considered. Mag $(\tilde{A})$ is used to rank fuzzy numbers. The magnitude of a triangular fuzzy number $\tilde{A}$ shows the data on every membership degree.

Hence,

$$\text{Mag}(\tilde{A}) = \left(\frac{a* + 4a_0 - a_*}{4}\right) = \left(\frac{\underline{a} + \overline{a} + a_0}{4}\right). \tag{4}$$

For any two triangular fuzzy numbers $\tilde{A} = (a_0, a_*, a^*)$ and $\tilde{B} = (b_0, b_*, b^*)$ in $F(R)$, we define the ranking of $\tilde{A}$ and $\tilde{B}$ by comparing the Mag $(\tilde{A})$ and Mag $(\tilde{B})$.

(i) $\tilde{A} \succeq \tilde{B}$ iff Mag $(\tilde{A}) \geq$ Mag $(\tilde{B})$.
(ii) $\tilde{A} \preceq \tilde{B}$ iff Mag $(\tilde{A}) \leq$ Mag $(\tilde{B})$.
(iii) $\tilde{A} \approx \tilde{B}$ iff Mag $(\tilde{A}) =$ Mag $(\tilde{B})$.

2.2 Arithmetic operations of triangular fuzzy number

As discussed above, any triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3)$ may be transformed into parametric form. So for arbitrary triangular fuzzy numbers $\tilde{A} = (a_0, a_*, a^*)$ and $\tilde{B} = (b_0, b_*, b^*)$, the arithmetic operations are defined by $\tilde{A} * \tilde{B} = (a_0 * b_0, a_* \vee b_*, a^* \vee b^*)$ where $* = \{+, -, \times, \div\}$. That is, it is dependent upon both location index and fuzziness index functions. The location index number is taken in the ordinary arithmetic, and the fuzziness index functions are treated to satisfy the lattice rule which is least upper bound in the lattice *L*. We define $A \vee B = \max\{A, B\}$ and $A \wedge B = \min\{A, B\}$ for all $a, b \in L$.

In particular for any two fuzzy numbers $\tilde{A} = (a_0, a_*, a^*)$ and $\tilde{B} = (b_0, b_*, b^*)$, we define:

(i) Addition:

$$\begin{aligned}\widetilde{A} + \widetilde{B} &= (a_0, a_*, a^*) + (b_0, b_*, b^*) \\ &= (a_0 + b_0, \max\{a_*, b_*\}, \max\{a^*, b^*\})\end{aligned} \tag{5}$$

(ii) Subtraction:

$$\begin{aligned}\widetilde{A} - \widetilde{B} &= (a_0, a_*, a^*) - (b_0, b_*, b^*) \\ &= (a_0 - b_0, \max\{a_*, b_*\}, \max\{a^*, b^*\})\end{aligned} \tag{6}$$

(iii) Multiplication:

$$\begin{aligned}\widetilde{A} \times \widetilde{B} &= (a_0, a_*, a^*) \times (b_0, b_*, b^*) \\ &= (a_0 \times b_0, \max\{a_*, b_*\}, \max\{a^*, b^*\})\end{aligned} \tag{7}$$

(iv) Division:

$$\begin{aligned}\widetilde{A} \div \widetilde{B} &= (a_0, a_*, a^*) \div (b_0, b_*, b^*) \\ &= (a_0 \div b_0, \max\{a_*, b_*\}, \max\{a^*, b^*\})\end{aligned} \tag{8}$$

3 Mathematical formulation of fuzzy transportation problem with mixed constraints

The mathematical formulation is given by

$$\begin{aligned} &\text{Min } (\tilde{z}) = \sum_{i=1}^{r}\sum_{j=1}^{s} \tilde{C}_{ij}\tilde{x}_{ij} \\ &\text{subject to } \sum_{j=1}^{s} \tilde{x}_{ij} \preceq / \approx / \succeq \tilde{A}_i \qquad (i = 1, 2, \ldots, r) \\ &\qquad \sum_{i=1}^{r} \tilde{x}_{ij} \preceq / \approx / \succeq \tilde{B}_j \qquad (j = 1, 2, \ldots, s) \\ &\qquad \text{and } \tilde{x}_{ij} \succeq \tilde{0}, \ \forall \ i, j \end{aligned} \tag{9}$$

Let $\tilde{C}_{ij}$ be the shifting amount of the stock from supply node *i* to demand node *j*. Let $\tilde{A}_i$ represent the amount of the stock accessible at supply node *i*, and $\tilde{B}_j$ be the amount of the stock required at a demand node *j*, and $\tilde{x}_{ij}$ denotes the amount of stock shifted from supply node *i* to demand node *j* in order to reduce the total transportation cost.

The problem can also be represented as in Table 1.

Now use follow the instruction given below to assign the supply and demand units:

For combination $\{\preceq \tilde{A}, \approx \tilde{B}\}$, the most desirable allocation is $\begin{cases} \tilde{B}, \ \tilde{A} \succeq \tilde{B} \\ \tilde{A}, \ \tilde{A} \prec \tilde{B} \end{cases}.$

Table 1 Fuzzy transportation problem identity

	Destination					
Source		1	2		s	Supply
	1	$\tilde{C}_{11}$	$\tilde{C}_{12}$	$\cdots$	$\tilde{C}_{1s}$	$\preceq / \approx / \succeq \tilde{A}_1$
	2	$\tilde{C}_{21}$	$\tilde{C}_{22}$	$\cdots$	$\tilde{C}_{2s}$	$\preceq / \approx / \succeq \tilde{A}_2$
	$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$
	r	$\tilde{C}_{r1}$	$\tilde{C}_{r2}$	$\cdots$	$\tilde{C}_{rs}$	$\preceq / \approx / \succeq \tilde{A}_r$
	Demand	$\preceq / \approx / \succeq \tilde{B}_1$	$\preceq / \approx / \succeq \tilde{B}_2$	$\cdots$	$\preceq / \approx / \succeq \tilde{B}_s$	

For combination $\{\succeq \tilde{A}, \approx \tilde{B}\}$, the most desirable allocation is $\tilde{B}$.

For combination $\{\preceq \tilde{A}, \preceq \tilde{B}\}$, the most desirable allocation is $\tilde{0}$.

For combination $\{\approx \tilde{A}, \approx \tilde{B}\}$, the most desirable allocation is minimum of $\{\tilde{A}, \tilde{B}\}$.

For combination $\{\succeq \tilde{A}, \succeq \tilde{B}\}$, the most desirable allocation is maximum of $\{\tilde{A}, \tilde{B}\}$.

For combination $\{\succeq \tilde{A}, \preceq \tilde{B}\}$, the most desirable allocation is $\begin{cases} \tilde{B}, \tilde{A} \succeq \tilde{B} \\ \tilde{A}, \tilde{A} \prec \tilde{B} \end{cases}$.

3.1 Theorem

The optimal more for less solution of a mixed constraints fuzzy transportation problem is an optimal solution of a modified fuzzy transportation problem by varying the sign of rows and columns containing negative Modi indices from $\preceq$ to $\approx$ and $\approx$ to $\succeq$.

Proof. The presence of a more for less circumstance needs just one condition, namely the presence of a position with a non-positive fuzzy Modi index (also called shadow price).

From the optimal solution, the shadow prices are effectively determined by using following steps:

(i) Assign $\tilde{u}_i + \tilde{v}_j = \tilde{c}_{ij}$ for all allocated cells.

(ii) Assign $\tilde{u}_i = 0$ and determine $\tilde{u}_i$ and $\tilde{v}_j$ values from the system of equations obtained from transportation problem.

(iii) Find $\tilde{u}_i + \tilde{v}_j$ for each unallocated (i, j) as shadow price.

Therefore, the existence of a negative shadow prices at a cell (i,j), $\tilde{u}_i + \tilde{v}_j$ shows that we can accomplish the accessibility of ith supply node/the requirement of the jth demand node at the most extreme conceivable level. Formulate a new fuzzy transportation problem by varying the sign $\preceq$ to $\approx$ and $\approx$ to $\succeq$ in the corresponding rows and columns containing non-positive Modi indices.

It can be seen that rows and column having negative Modi indices in the newly determined fuzzy transportation problem with mixed constraint is having in all the rows in the equations. Hence, any solution of the newly formed solution is an optimal solution of the primal problem.

Thus, the optimal more for less solution to the primal problem is determined from the optimal more for less solution of the newly determined fuzzy transportation problem.

3.2 Novelty in the proposed method

In this, the zero point is also considered for the solution. Due to this, the triangular membership functions is used. The proposed method has the following changes in the existing techniques to get the most optimal solutions:

- Zero point is also considered in the more for less solution
- Modi index is used which helps to find the minimal solution better.
- Able to find most optimal solutions with lesser number of iterations.

The proposed method is implemented on a fuzzy transportation problem with 3*4 mixed constraint transportation problem.

4 Algorithm to find more for less solution

In this section, initially we find basic feasible solution to the problem and then analyze the more for less situation by using theorem.

(i) Transform the given triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3)$ into the parametric form $\tilde{A} = (a_0, a_*, a^*)$.

(ii) Sum the row opportunity cost table and column opportunity cost table and find the total opportunity cost (TOC) table.

(iii) Applying the proposed ranking function, select the maximum cost coefficient $\tilde{C}_{ij}$.

(iv) Choose the smallest cost coefficient in the corresponding row (or) column of this largest cost coefficient $\tilde{C}_{ij}$.

(v) Assign the most possible quantity to the least cost coefficients. For this we follow the instructions to find the supply and demand cost.

(vi) Choose arbitrarily when tie occurs.

(vii) Repeat the steps (iii) to (vi) till the basic feasible solution is determined. For the obtained basic solution of the fuzzy transportation problem, the Modi index table is constructed. If no negative Modi indices exist, then this is an optimal solution to the given problem (no more for less solution situation is present).

(viii) If exists formulate, a new transportation problem with mixed constraints by applying theorem that is varying the sign $\preceq$ to $\approx$ and $\approx$ to $\succeq$ in the corresponding rows and columns containing negative Modi indices.

(ix) Repeat the above steps until there are no negative Modi indices. The optimal solution determined is an optimal more for less solution of the original problem.

Note: we need $m + n - 1$ allocated cells for calculating Modi indices. So we keep the cells would be loaded using the proposed process even with a load of zero.

5 Numerical example

Consider a fuzzy transportation problem with mixed constraints discussed by Pandian and Natarajan whose parameters are triangular fuzzy numbers in the form of (a_1, a_2, a_3). In this, the fuzzy transportation problem is applied for the 3*4 as sources and destination (Table 2).

The problem is solved by using the steps in the algorithm in Sect. 4.

By using step (i), we get Table 3.

Apply the steps (i) and (ii), we get Table 4.

Using the proposed algorithm we obtain the following allocation (Table 5).

The allocation schedule is

$$\tilde{x}_{11} = (5,\ 4-4S,\ 4-4S),\ \tilde{x}_{21} = (3,\ 4-4S,\ 4-4S),\ \tilde{x}_{22} = (10,\ 4-4S,\ 4-4S),$$
$$\tilde{x}_{23} = (0,\ 3-3S,\ 3-3S),\ \tilde{x}_{33} = (0,\ 6-6S,\ 6-6S).$$

Table 2 Mixed constraint fuzzy transportation problem

(1, 2, 3)	(2, 5, 8)	(2, 4, 6)	≈(2, 5, 8)
(2, 6, 10)	(1, 3, 5)	(0, 1, 2)	⪰(3, 6, 9)
(4, 8, 10)	(3, 9, 15)	(1, 2, 3)	⪯(3, 9, 15)
≈(4, 8, 12)	⪰(8, 10,12)	⪯(3, 5, 7)	

Hence by the proposed algorithm, the initial basic feasible solution is $\min \tilde{z} = (58,\ 4-4S,\ 4-4S)$ where $0 \le S \le 1$ can be properly decided by the decision maker (Table 6).

Because the first row, second and third columns contains non-positive fuzzy Modi indices, we construct the modified transportation problem with mixed constraints by using theorem (Table 7).

Again by applying our proposed method, we obtain the following allotment (Table 8).

The initial basic solution for the newly constructed problem is $\tilde{x}_{11} = (8,\ 4-4S,\ 4-4S)$, $\tilde{x}_{12} = 0$, $\tilde{x}_{22} = (10,\ 3-3S,\ 3-3S)$, $\tilde{x}_{23} = 0$, $\tilde{x}_{33} = (5,\ 6-6S,\ 6-6S)$ (Table 9).

Hence each one of the fuzzy Modi indices are nonnegative, the present solution is an optimal solution of the newly formed fuzzy transportation problem.

Therefore by using theorem, the more for less solution for the given primal problem is $\tilde{x}_{11} = (8,\ 4-4S,\ 4-4S)$, $\tilde{x}_{21} = 0$, $\tilde{x}_{22} = (10,\ 3-3S,\ 3-3S)$, $\tilde{x}_{23} = 0, \tilde{x}_{33} = (5,\ 6-6S,\ 6-6S)$, and the minimum cost is $(56,\ 6-6S,\ 6-6S)$.

The equivalent fuzzy optimal transportation cost in the primal form of (a_1, a_2, a_3) is $\min \tilde{z} = (50, 56,\ 62)$.

5.1 Comparative study

In existing, once the zero point is attained, the optimal solutions is determined. But, in the proposed even with the zero point is attained, the process is continued till it reaches the negative Modi indices. The proposed method is best suitable for the fuzzy transportation problem better as compared to the other.

A comparative study made with Pandian and Natarajan (2010) is presented in table, and a graphical representation is given in Fig. 1 (Table 10).

6 Conclusion

In this paper, we have considered a fuzzy transportation problem with mixed constraints containing triangular fuzzy numbers and proposed a different process to obtain the initial basic feasible solution to the problem without

Table 3 Parametric form of fuzzy transportation problem

(2, 1 − S, 1 − S)	(5, 3 − 3S, 3 − 3S)	(4, 2 − 2S, 2 − 2S)	≈(5, 3 − 3S, 3 − 3S)
(6, 4 − 4S, 4 − 4S)	(3, 2 − 2S, 2 − 2S)	(1, 1 − S, 1 − S)	⪰(6, 3 − 3S, 3 − 3S)
(8, 4 − 4S, 4 − 4S)	(9, 6 − 6S, 6 − 6S)	(2, 1 − S,1 − S)	⪯(9, 6 − 6S, 6 − 6S)
≈(8, 4 − 4S, 4 − 4S)	⪰(10, 2 − 2S,2 − 2S)	⪯(5, 2 − 2S, 2 − 2S)	

Table 4 Representation of total opportunity cost table

(0, 1 − S, 1 − S)	(5, 3 − 3S, 3 − 3S)	(5, 2 − 2S, 2 − 2S)	≈(5, 3 − 3S, 3 − 3S)
(9, 4 − 4S, 4 − 4S)	(2, 2 − 2S, 2 − 2S)	(0, 1 − S,1 − S)	⪰(6, 3 − 3S, 3 − 3S)
(12, 4 − 4S, 4 − 4S)	(13, 6 − 6S, 6 − 6S)	(1, 1 − S,1 − S)	⪯(9, 6 − 6S, 6 − 6S)
≈(8, 4 − 4S, 4 − 4S)	⪰(10, 2 − 2S, 2 − 2S)	⪯(5, 2 − 2S, 2 − 2S)	

Table 5 Initial basic feasible solution based on fuzziness index and location index

(5, 4 − 4S, 4 − 4S)			≈(5, 3 − 3S, 3 − 3S)
(3, 4 − 4S, 4 − 4S)	(10, 3 − 3S, 3 − 3S)	(0, 3 − 3S, 3 − 3S)	⪰(6, 3 − 3S, 3 − 3S)
		(0, 6 − 6S, 6 − 6S)	⪯(9, 6 − 6S, 6 − 6S)
≈(8, 4 − 4S, 4 − 4S)	⪰(10, 2 − 2S, 2 − 2S)	⪯(5, 2 − 2S, 2 − 2S)	

Table 6 Fuzzy Modi index table

$\tilde{v}_1$	$\tilde{v}_2$	$\tilde{v}_3$	$\tilde{u}_i$
(2, 1 − S, 1 − S)	(− 1, 2 − 2S, 2 − 2S)	(− 3, 1 − S, 1 − S)	(− 4, 1 − S, 1 − S)
(6, 4 − 4S, 4 − 4S)	(3, 2 − 2S, 2 − 2S)	(1, 1 − S,1 − S)	$\tilde{0}$
(7, 4 − 4S, 4 − 4S)	(4, 2 − 2S, 2 − 2S)	(2, 1 − S,1 − S)	(1, 1 − S,1 − S)
(6, 4 − 4S, 4 − 4S)	(3, 2 − 2S, 2 − 2S)	(1, 1 − S,1 − S)	

Table 7 Newly constructed fuzzy transportation with mixed constraints

$\tilde{v}_1$	$\tilde{v}_2$	$\tilde{v}_3$	$\tilde{u}_i$
(2, 1 − S,1 − S)	(5, 3 − 3S, 3 − 3S)	(4, 2 − 2S, 2 − 2S)	⪰(5, 3 − 3S,3 − 3S)
(6, 4 − 4S, 4 − 4S)	(3, 2 − 2S, 2 − 2S)	(1, 1 − S,1 − S)	⪰(6,3 − 3S, 3 − 3S)
(8, 4 − 4S, 4 − 4S)	(9, 6 − 6S, 6 − 6S)	(2, 1 − S,1 − S)	⪯(9,6 − 6S, 6 − 6S)
≈(8, 4 − 4S, 4 − 4S)	⪰(10, 2 − 2S, 2 − 2S)	≈(5, 2 − 2S,2 − 2S)	

Table 8 Allocation table in terms of location index and fuzziness index

$\tilde{v}_1$	$\tilde{v}_2$	$\tilde{v}_3$	
(8, 4 − 4S, 4 − 4S)	(0, 3 − 3S, 3 − 3S)		⪰(5, 3 − 3S, 3 − 3S)
	(10, 3 − 3S, 3 − 3S)	(0, 3 − 3S, 3 − 3S)	⪰(6, 3 − 3S, 3 − 3S)
		(5, 6 − 6S, 6 − 6S)	⪯(9, 6 − 6S, 6 − 6S)
≈ (8, 4 − 4S, 4 − 4S)	⪰(10, 2 − 2S, 2 − 2S)	≈ (5, 2 − 2S, 2 − 2S)	

changing to its crisp equivalent problem. Also we analyze the more for less situation to the problem, and it is verified that the fuzzy optimal more for less solution obtained by the proposed algorithm has reduced spreads compared to the existing methods which provides more flexibility to the decision maker. The presence of a position with a non-

Table 9 Fuzzy Modi index table for the current problem

$\tilde{v}_1$	$\tilde{v}_2$	$\tilde{v}_3$	
$(2, 1 - S, 1 - S)$	$(5, 3 - 3S, 3 - 3S)$	$(3, 3 - 3S, 3 - 3S)$	$(2, 3 - 3S, 3 - 3S)$
$(0, 1 - S, 1 - S)$	$(3, 2 - 2S, 2 - 2S)$	$(1, 1 - S, 1 - S)$	$\tilde{0}$
$(1, 1 - S, 1 - S)$	$(4, 2 - 2S, 2 - 2S)$	$(2, 1 - S, 1 - S)$	$(1, 1 - S, 1 - S)$
$(0, 1 - S, 1 - S)$	$(3, 2 - 2S, 2 - 2S)$	$(1, 1 - S, 1 - S)$	

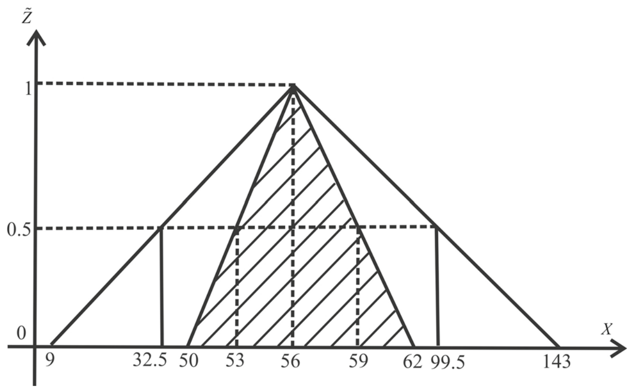

Fig. 1 Triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3) = (\alpha, m, \beta)$

Table 10 Comparative study of example

	Fuzzy optimal more for less solution of proposed method	Fuzzy optimal more for less solution of Pandian and Natarajan (2010)
min $\tilde{z}$	(50, 56, 62)	(9, 56, 143)
For $S = 0$	(50, 62)	(9, 143)
For $S = 0.5$	(53, 59)	(32.5, 99.5)
For $S = 1$	56	56

positive plant to markets transporting shadow prices shows that there is a more for less situation to the problem. The identification of a shadow price can also be utilized as an alternate solution algorithm for finding the solution of certain transportation problems. We provided a numerical example to explain the significance of defining a more for less situation and show the efficiency of the proposed method. In future, like to extend the zero point method for the trapezoidal function.

Author contributions All the three authors were mutually worked together to propose a new technique and convert into a manuscript format for finding optimal solution in fuzzy transportation problem.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The proposed technique is a new technique, and it is not published in any other journal.

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