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Optimal solution for fuzzy transportation problem using median ranking

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Abstract
In this paper, a new ranking method known as median ranking is used to convert fuzzy transportation problems to crisp valued transportation problems and then solve them by using the Max-Min technique. We can apply this ranking to both types of fuzzy numbers such as odd numbers of fuzzy numbers and even numbers of fuzzy numbers. Using the method, we can reach an optimal solution of balanced as well as unbalanced FTP.

Keywords: Dodecagonal fuzzy number, hendecagonal fuzzy number, FTP (Fuzzy transportation problem), UBFTP (unbalanced fuzzy transportation problem), BFTP (balanced fuzzy transportation problem), median

Introduction
A transportation problem represents a particular type of linear programming problem used for optimally allocating resources. It works in a way of minimizing a cost function. Because of their uncertainty, fuzzy numbers and values are used in various fields such as experimental sciences, Artificial Intelligence, etc.

L.A. Zadeh introduced the fuzzy set theory [1], which is very useful in real-life situations. A fuzzy transportation problem is a transportation problem with the quantities like supply, demand, and transportation cost in fuzzy numerals.

There are different methods for ranking fuzzy numbers. S. Sathya Geetha, and K. Selvkumari [2] proposed a new method for solving FTP using pentagonal fuzzy numbers using the range technique for ranking in 2020. The Sub–Interval Average Method for Ranking of Linear Fuzzy Numbers was proposed by S. Kamalnath and Rameshan Natarajan [3], Dr. A. Sahya Sudha, S. Karunam [4] proposed a new ranking method using heptagonal Fuzzy number. New ranking function of the Nanogonal Fuzzy Number was proposed by K. Deepika, S. Rekha [5]. Kirtiwant P. Ghadle and Priyanka A. Pathade [6] solved FTP with generalized Hexagonal and generalized Octagonal Fuzzy Number by ranking method. A suitable defuzzification method to find minimum transportation cost using decagonal fuzzy number was developed by S. Nagadevi and G.M. Rosario [7]. Edithstine Rani Mathew [8], Sunny Joseph Kalayathankal proposed a new ranking method using dodecagonal fuzzy numbers to solve FTP. Sanjivani Ingle and Kirtiwant Ghadle [9] derived two formulas related to odd and even numbers of fuzzy numbers for the optimal solution to Fuzzy Assignment Problem.

In this paper, we introduced a new ranking technique considering elements fuzzy numbers as ungrouped data, and according to the odd or even number of elements we apply the formula of median and convert the fuzzy number into a crisp value. Then using Max-Min Method [2] we will get an optimal solution. This ranking can be applicable for balanced and unbalanced fuzzy transportation problems.

The first two examples are BFTP and UBFTP using dodecagonal Fuzzy Numbers. The next Two are BFTP and UBFTP using hendecagonal Fuzzy Numbers.

Preliminaries Fuzzy Number [9]:
A fuzzy number is a convex normalized fuzzy set on the real line R such that
1. There exists at least one $y \in R$ with $\mu \tilde{A}(y) = 1$.
2. $\mu_{\tilde{A}}(y)$ is piecewise continuous.

Dodecagonal fuzzy number [8]
The membership function of dodecagonal fuzzy number

$\tilde{A} = (a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, a_{12})$

where $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, a_{12}$ are real numbers, are given by,

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x \le a_1 \\ k_1 \frac{x-a1}{a2-a1}, & a_1 \le x \le a_2 \\ k_1, & a_2 \le x \le a_3 \\ k_1 + (1-k_1)\frac{x-a3}{a4-a3}, & a_3 \le x \le a_4 \\ k_2, & a_4 \le x \le a_5 \\ k_2 + (1-k_2)\frac{x-a5}{a6-a5} & a_5 \le x \le a_6 \\ 1, & a_6 \le x \le a_7 \\ k_2 + (1-k_2)\frac{a8-x}{a8-a7} & a_7 \le x \le a_8 \\ k2, & a_8 \le x \le a_9 \\ k_1 + (1-k_1)\frac{a10-x}{a10-a9} & a_9 \le x \le a_{10} \\ k_1, & a_{10} \le x \le a_{11} \\ k_1 \frac{a12-x}{a12-a11}, & a_{11} \le x \le a_{12} \\ 0, & a_{12} \le x \end{cases}$$

Where $0 < k_1 < k_2 < 1$

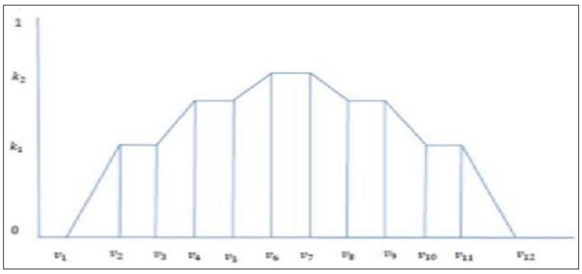

Fig 1: Graphical representation of dodecagonal fuzzy

Hendecagonal Fuzzy Number [10]
A Hendecagonal fuzzy number HeD is denoted as (a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}), and the membership function is defined as

$$\begin{cases} \frac{1}{5}\frac{x-a1}{2-a1} & a_1 \le x \le a_2 \\ \frac{1}{5} + \frac{1}{5}\frac{x-a2}{a3-a2} & a_2 \le x \le a_3 \\ \frac{2}{5} + \frac{1}{5}\frac{x-a3}{a4-a3} & a_3 \le x \le a_4 \\ \frac{3}{5} + \frac{1}{5}\frac{x-a4}{a5-a4} & a_4 \le x \le a_5 \\ \frac{4}{5} + \frac{1}{5}\frac{x-a5}{a6-a5} & a_5 \le x \le a_6 \\ \frac{4}{5} - \frac{1}{5}\frac{x-a7}{a8-a7} & a_7 \le x \le a_8 \\ \frac{3}{5} - \frac{1}{5}\frac{x-a8}{a9-a8} & a_8 \le x \le a_9 \\ \frac{2}{5} - \frac{1}{5}\frac{x-a9}{a10-a9} & a_9 \le x \le a_{10} \\ -\frac{1}{5}\frac{11-x}{a11-a10} & a_{10} \le x \le a_{11} \\ 0, & \text{otherwise} \end{cases}$$

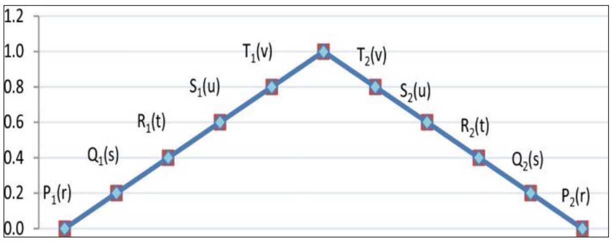

Fig 2: Hendecagonal fuzzy number

Proposed Formula: (Lokare and Ghadle) A] for even fuzzy numbers

R (a_1, a_2, a_3, a_4, ………., a_{n-1}, a_n) = $\frac{Th}{2}$ Mean of $\left(\frac{n}{2}\right)$ term and $(n+1)$ ^{the} term

Ex:
1. R (1, 12, 23, 34, 45, 56) = Mean of a_3 and a_4

$= \left(\frac{23+34}{2}\right) = \frac{57}{2} = 28.5$

2. R (2, 4, 6, 8, 10, 12, 14, 16) = Mean of a_4 and a_5

$= \frac{8+10}{2} = \frac{18}{2} = 9$

B. For odd fuzzy numbers

$R(a_1, a_2, a_3, a_4, \ldots\ldots, a_{n-1}, a_n, a_2) = \left(\frac{n+1}{n+1}\right)^{\text{the}}$ term

Ex:
1. R (1, 2, 3, 4, 5) = $\left(\frac{5+1}{2}\right)^{\text{th}}$ $\text{term}_3 = a = 3$
2. R (3, 4, 6, 8, 9, 11, 12) = $\left(\frac{7+1}{2}\right)^{\text{th}}$ term $= {}_4a = 8$

Algorithm
Step 1: Construct the transportation table and check whether it is BTP or UBTP.

Step 2: If the problem is unbalanced then make it balanced by adding a dummy row or column as per the requirement of supply and demand, otherwise go to step 3.

Step 3: Convert the fuzzy transportation table to a crisp transportation table using the proposed ranking method.

Step 4: Use the Max-Min method [2] to solve the problem's optimal solution.

Numerical Examples: A. Consider the balanced fuzzy transportation problem using Dodecagonal Fuzzy Numbers

The crisp transportation table using the proposed ranking is as follows:

	S1	S2	S3	S4	Supply
F1	2.5	3.5	11.5	7.5	6.5
F2	1.5	0.5	6.5	1.5	1.5
F3	5.5	8.5	15.5	9.5	11
Demand	7.5	5.5	3.5	2.5	

	S1	S2	S3	S4	Supply
F1	(-3, -2, - 1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17)	(2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)	(-1, 0, 1, 3, 5, 6, 7, 8, 10, 12, 13, 14)
F2	(-4, -3, -2, - 1, 0, 1, 2, 3, 4, 5, 6, 7)	(-5, -4, -3, -2, - 1, 0, 1, 2, 3, 4, 5, 6)	(0, 1, 2, 4, 5, 6, 7, 8, 9, 11, 12, 13)	(-5, -4, -3, - 1, 0, 1, 2, 4, 5, 6, 7, 9)	(-4, -3, -2, - 1, 0, 1, 2, 3, 4, 5, 6, 7)
F3 Demand	(-2, - 1, 0, 1, 2, 4, 7, 9, 11, 12, 15, 19) (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)	(1, 2, 3, 6, 7, 8, 9, 10, 12, 13, 15, 16) (- 2, 0, 1, 2, 3, 5, 6, 7, 8, 10, 11, 12)	(8, 9, 11, 12, 14, 15, 16, 17, 18, 21, 22, 23) (-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(2, 3, 5, 6, 8, 9, 10, 11, 12, 15, 16, 17) (-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(2, 4, 5, 6, 8, 10, 12, 13, 15, 17, 18, 19)

Using the Max-Min technique we got first allocations as

	S1	S2	S3	S4	Supply	$\frac{Max - Min}{4}$
F1	2.5	3.5	11.5	7.5	6.5	2.25
F2	1.5	0.5	6.51.5	1.5	1.5	1.75
F3	5.5	8.5	15.5	9.5	11	2.5
Demand	7.5	5.5	3.5	2.5		
$\frac{Max - Min}{3}$	1.33	2.66	3	2.66		

For next allocation

	S1	S2	S3	S4	Supply	$\frac{Max - Min}{4}$
F1	2.5	3.55.5	11.5	7.5	6.5	2.25
F2	1.5	0.5	6.51.5	1.5	0	-
F3	5.5	8.5	15.5	9.5	11	2.5
Demand	7.5	5.5	3.5	2.5		
$\frac{Max - Min}{2}$	1.5	2.5	2	1		

For Next Allocation

	S1	S2	S3	S4	Supply	$\frac{Max - Min}{3}$
F1	2.5	3.55.5	11.5	7.5	1	3
F2	1.5	0.5	6.51.5	1.5	0	-
F3	5.5	8.5	15.5	9.5	11	3.33
Demand	7.5	0	3.5	2.5		
$\frac{Max - Min}{2}$	1.5	-	2	1		

Continuing this way we have all allocations as

	S1	S2	S3	S4
F1	2.5	3.55.5	11.5[1]	7.5
F2	1.5	0.5	6.51.5	1.5
F3	5.57.5	8.5	15.5[1]	9.52.5

We got the optimal solution as: (5.5) (7.5) + (3.5) (5.5) + (6.5) (1.5) + (11.5) (1) + (9.5) (2.5) + (15.5) (1) = 121

Sr.NO	Ranking Technique	Optimal Solution
1	Range Technique	541
2	Sub interval Average Technique	125.95
3	Median Ranking	121

Consider unbalanced FTP using dodecagonal fuzzy numbers this is UFTP, we convert it into BFTP by adding a dummy row
Using the proposed ranking we get

	S1	**S2**	**S3**	**S4**	**Supply**
F1	(-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 1 7)	(2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)	(-1, 0, 1, 3, 5, 6, 7, 8, 10, 12, 13, 14)
F2	(-4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7)	(-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6)	(0, 1, 2, 4, 5, 6, 7, 8, 9, 11, 12, 13)	(-5, -4, -3, -1, 0, 1, 2, 4, 5, 6, 7, 9)	(-4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7)
F3	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(1, 2, 3, 6, 7, 8, 9, 10, 12, 13, 15, 16)	(8, 9, 11, 12, 14, 15, 16, , 17, 18, 21, 2, 23)	(2, 3, 5, 6, 8, 9, 10, 11, 12, 15, 16, 1 7)	**(**0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13**)**
Demand	(2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 1 3)	(-2, 0, 1, 2, 3, 5, 6, 7, 8, 10, 11, 12)	(-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	
	S1	S2	S3	S4 | Supply	
F1	2.5	3.5	11.5	7.5 | 6.5	
F2	1.5	0.5	6.5	1.5 | 1.5	
	S1	S2	S3	S4	Supply
F1	(-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 1 7)	(2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)	(-1, 0, 1, 3, 5, 6, 7, 8, 10, 12, 13, 14)
F2	(-4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7)	(-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6)	(0, 1, 2, 4, 5, 6, 7, 8, 9, 11, 12, 13)	(-5, -4, -3, -1, 0, 1, 2, 4, 5, 6, 7, 9)	(-4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7)
F3	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(1, 2, 3, 6, 7, 8, 9, 10, 12, 13, 15, 16)	(8, 9, 11, 12, 14, 15, 16, 17, 18, 21, 2 2, 23)	(2, 3, 5, 6, 8, 9, 10, 11, 12, 15, 16, 1, 7)	**(**0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13**)**
F4	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(-2, -1, 0, 1, 2, 3, 6, 7, 9, 10, 11, 12**)**
Demand	(2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 1 3)	(-2, 0, 1, 2, 3, 5, 6, 7, 8, 10, 11, 12)	(-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	(-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)	

F3	**5.5**	**8.5**	**15.5**	**9.5**	**6.5**
	0	0	0	0	4.5
Demand	7.5	5.5	3.5	2.5	

Using the Max-Min method, we get

	S1	**S2**	**S3**	**S4**
F1	2.52.5	3.5^4	11.5	7.5
F2	1.5	0.51.5	6.5	1.5
F3	5.5^5	8.5	15.5	9.51.5
F4	0	0	03.5	01

Optimal solution is: (2.5) (2.5) + (3.5) (4) + (0.5) (1.5) + (5.5) (5) + (9.5) (1.5) + (0) (3.5) + (0) (1) = 62.75

Table of Comparison

Sr. No	**Ranking Technique**	**Optimal Solution**
1	Range Technique	341
2	Sub interval Average Technique	63.5
3	Median Ranking	62.75

Consider balanced fuzzy transportation problem using Hendecagonal Fuzzy Number

	D1	**D2**	**D3**	**Supply**
S1	(1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21)	(2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22)	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)
S2	(3, 7, 11, 13, 17, 21, 22, 25, 29, 32, 40)	(2, 4, 6, 8, 9, 13, 15, 16, 18, 20, 21)	(2, 3, 7, 8, 9, 11, 13, 15, 16, 21, 33)	(2, 4, 6, 8, 10, 12, 14, 16, 18, 2 0, 22)
S3	(1, 2, 3, 4, 7, 10, 13, 15, 16, 17, 22)	(5, 8, 10, 13, 16, 21, 23, 28, 31, 32)	(4, 6, 7, 9, 10, 11, 18, 23, 24, 26, 27)	(11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21)
Demand	(3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33)	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(1, 3, 5, 7, 9, 10, 13, 14, 15, 16, 17)	

The crisp transportation table using the proposed ranking is as follows:

	D1	**D2**	**D3**	**Supply**
S1	11	12	6	6
S2	21	13	11	12
S3	10	21	11	16
Demand	18	6	10	

Using the Max-Min technique we got first allocations as

	D1	**D2**	**D3**	**Supply**	$\frac{Max - Min}{3}$
S1	11	12	6	6	2
S2	21	13	11	12	3.33
S3	1016	21	11	16	3.66
Demand	18	6	10		
$\frac{Max - Min}{3}$	3.66	3	1.66		

Proceeding in this way we got final allocations as

	D1	D2	D3
S1	11^2	12	64
S2	21	13^6	11^6
S3	1016	21	11

Optimal solution is: (11) (2) + (10) (16) + (13) (6) + (6) (4) + (11) (6) = 350

Table of Comparison

Sr. NO	Ranking Technique	Optimal Solution
1	Range Technique	834
2	Sub interval Average Technique	353.24
3	Median Ranking	350

Consider unbalanced Fuzzy Transportation Problem using hendecagonal fuzzy numbers

This is UFTP, we convert it into BFTP by adding a dummy row

	S1	S2	S3	Supply
F1	(-3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7)	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10),	(-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44)
F2	(2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22)	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(-4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6)	(2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22)
F3	(3, 5, 7, 9, 11, 13, 14, 15, 16, 17, 18)	(1, 4, 5, 9, 10, 12, 13, 14, 15, 16, 17)	(-2, 0, 2, 4, 6, 8, 10, 12, 15, 17, 18)	(-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8)
Demand	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 3 3)	(4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44)	
	S1	S2	S3	Supply
F1	(-3, -2, - 1, 0, 1, 2, 3, 4, 5, 6, 7)	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10),	(-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(4, 8, 12, 16, 20, 24, 28, 3 2, 36, 40, 44)
F2	(2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22)	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(-4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6)	(2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22)
F3	(3, 5, 7, 9, 11, 13, 14, 15, 16, 17, 18)	(1, 4, 5, 9, 10, 12, 13, 14, 15, 16, 17)	(- 2, 0, 2, 4, 6, 8, 10, 12, 15, 17, 18)	(-2, - 1, 0, 1, 2, 3, 4, 5, 6, 7, 8)
F4	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)	(4, 5, 6, 78, 9, 10, 11, 12, 13, 14)
Demand	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11)	(3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33)	(4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44)	

Using the proposed ranking we get a crisp table as

	S1	S2	S3	Supply
F1	2	5	4	24
F2	12	6	1	12
F3	13	12	8	3
F4	0	0	0	9
demand	6	18	24	

Using the Max-Min method we have allocations as

	S1	S2	S3
F1	2	515	49
F2	12	6	112
F3	13	12	83
F4	06	03	0

Optimal solution is: (15) (5) + (4) (9) + (0) (6) + (0) (3) + (1) (12) + (8) (3) = 147

Table of Comparison

Sr. No	Ranking Technique	Optimal Solution
1	Range Technique	850
2	Sub interval Average Technique	148
3	Median Ranking	147

Conclusion

This paper has obtained an optimal solution for the fuzzy transportation problems with hendecagonal and dodecagonal fuzzy numbers using a new ranking technique.

We can apply the proposed ranking for any type of fuzzy number such as even or odd. Using the ranking we can solve balanced as well as unbalanced FTP and will get an optimal solution to compare to other methods of ranking considering elements of fuzzy numbers as ungrouped data.

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